Volume 14 NOVEMBER 1930 Number 11

BULLETIN
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American Association *of* Petroleum Geologists

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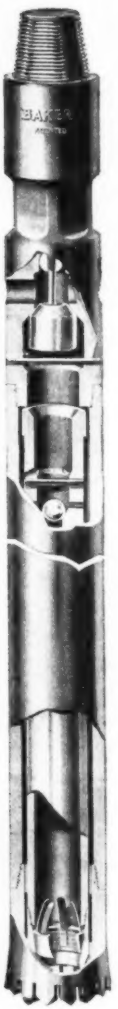
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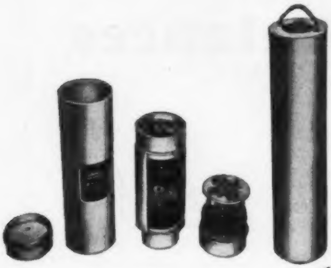


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NOVEMBER 1930

PETROLEUM POTENTIALITIES OF GULF COAST PETROLEUM PROVINCE OF TEXAS AND LOUISIANA[1]

DONALD C. BARTON[2]
Houston, Texas

ABSTRACT

A new vista of the petroleum potentialities of the Gulf Coast petroleum province of Texas and Louisiana has been opened by the developments of the past few years. The coastal salt-dome area has been extended eastward to, and across, Mississippi River. The area of good production has been extended southwestward to Refugio and may be expected to extend to the Rio Grande; it has been extended southward to Clay Creek, which lies in a hitherto practically non-productive zone, and seems probably to have been extended eastward to Terrebonne Parish, Louisiana. The maximum depth of production has been extended to 7,444 feet and the stratigraphic zone of good production has been extended down into the middle of the Claiborne. Deep and very deep salt domes have great potentialities, are being discovered in great numbers, but have certain drawbacks. The very deep salt ridges are unknown quantities. An enormously thick potentially productive stratigraphic section is present and offers great possibilities for production on such deep structures. A distinct tendency is shown for an increase of the Baumé gravity and gasoline content of the oil with increasing depth and in part with increasing stratigraphic depth. That change foreshadows a progressive change in the mean character of the oil of the future and gives the only suggestion, as yet, of a possible downward limit to production. The general magnitude of the recoverable reserves of oil in the Gulf Coast area of Texas and Louisiana at a shrewd guess is: surely at least 3,500,000,000 barrels, probably at least 5,500,000,000 barrels, and possibly at least 10,000,000,000 barrels.

INTRODUCTION

The thesis of this review of the petroleum potentialities of the Texas-Louisiana Gulf Coast is: (1) a new vista of petroleum potentialities has been opened by the developments of the past 3 years in the Gulf

[1]Read before the Association at the New Orleans meeting, March 20, 1930. Manuscript received by the editor, May 30, 1930.

[2]Consulting geologist and geophysicist.

Coast area of Texas and Louisiana, and (2) a drastic upward revision of the estimate of the effective petroleum reserves of the area is necessitated by those developments.

The area which is treated in this review extends from the Rio Grande to the eastern border of Louisiana and stretches back from the coast about 150 miles to an indefinite inner boundary. The area comprises essentially the Tertiary petroleum province of Texas and Louisiana.

The more recent previous estimates of the petroleum reserves of the area have been: the 1921 estimate of 2,100,000,000 barrels made in the coöperative survey of the oil reserves of the United States by the U. S. Geological Survey and The American Association of Petroleum Geologists; and the estimate made by the writer in 1928 of 2,300,000,000 barrels plus 1,000,000,000-3,000,000,000 barrels perhaps not recoverable. Most of the oil of the reserves of both estimates was postulated as occurring in the Miocene and Oligocene of salt domes in the "old" salt-dome area.

The limits of good production and of at least considerable reserves of oil have been extended eastward into the Mississippi delta, northward to Clay Creek, southwestward at least to Refugio and possibly to the Rio Grande, stratigraphically downward to include the Jackson and the Claiborne, and actually downward to 7,300 feet.

A new vista of the petroleum potentialities of the Gulf Coast petroleum province has been opened by these extensions of good production and requires a drastic revision of the estimate of the petroleum reserves of the area.

The estimate of those reserves which the writer presents is: that the ultimate production of oil in the area surely will be at least 3,500,000,000 barrels; probably at least 5,500,000,000 barrels; and possibly at least 10,000,000,000 barrels. Those reserves are composed of oil which can and ultimately will be produced by present-day or slightly improved methods of production at crude oil prices within the range of prices of the past decade. The efficiency of recovery of oil from oil sands commonly is believed to range from 25 to 50 per cent. The unrecoverable oil is not included within the estimated reserves.

All estimates of the amount of undiscovered reserves of oil are guesses — commonly bad guesses. The figures of the present estimate probably will have to be revised upward within the next decade, but they serve to give a concrete picture of the writer's evaluation of the petroleum potentialities of the Gulf Coast area of Texas and Louisiana on the basis of the data now available.

TABLE I

NEWLY DISCOVERED PRODUCTION EAST OF LAFAYETTE, LOUISIANA

Dome	*Parish*	*Depth (Feet)*	*Initial Production (Barrels per Day)*	*Remarks*
Sorrento	Ascension			Disappointing cap rock production. Little exploration of flanks
Fausse Pointe	Iberia-St. Martin	1,200	50	
White Castle	Iberville	5,836	75	
Bayou Bleu	Iberville	1,925	15	
Port Barre	St. Landry	3,763	800	
Bay St. Elaine	Terrebonne	680	P20	
Dog Lake	Terrebonne	1,062	10	
Lake Barre	Terrebonne	3,849	1,680	
Lake Pelto	Terrebonne	1,388	400	
East Bay Junop	Terrebonne	4,000	.....	Good showing
Caillou Island	Terrebonne	3,239	1,000	Also a 2,000-barrel well

P = pumped.

AREAL EXTENSION OF PROBABLY GOOD PRODUCTION

The area of good production has been extended northward and southwestward from the old compact area of good production in southeastern Texas and southwestern Louisiana and the indications are that it has been extended eastward (Fig. 1).

The eastern limit of good production probably has pushed eastward across Mississippi River. The eastern limit formerly was regarded as lying between Jennings and Lafayette, although small deposits of oil were known to exist farther east, at Anse la Butte, New Iberia, and Bayou Boullion. Oil has been discovered on eleven of the newly discovered geophysical salt domes east of Lafayette. None of these oil fields has demonstrated its right to a rating of first or second class and it is distinctly disappointing that as yet no first-class producer has been completed in any of these new fields. Exploration, however, has not proceeded far in these fields; and the failure of a few wells to find good production is no reliable indication of the absence of potential good production on a salt dome. It took about 150 wells at Barber's Hill and more than 100 wells at Pierce Junction to establish good production. Although itself disappointing, the newly discovered production east of Lafayette is highly suggestive of possibly great potentialities of that area for first- and second-class production.

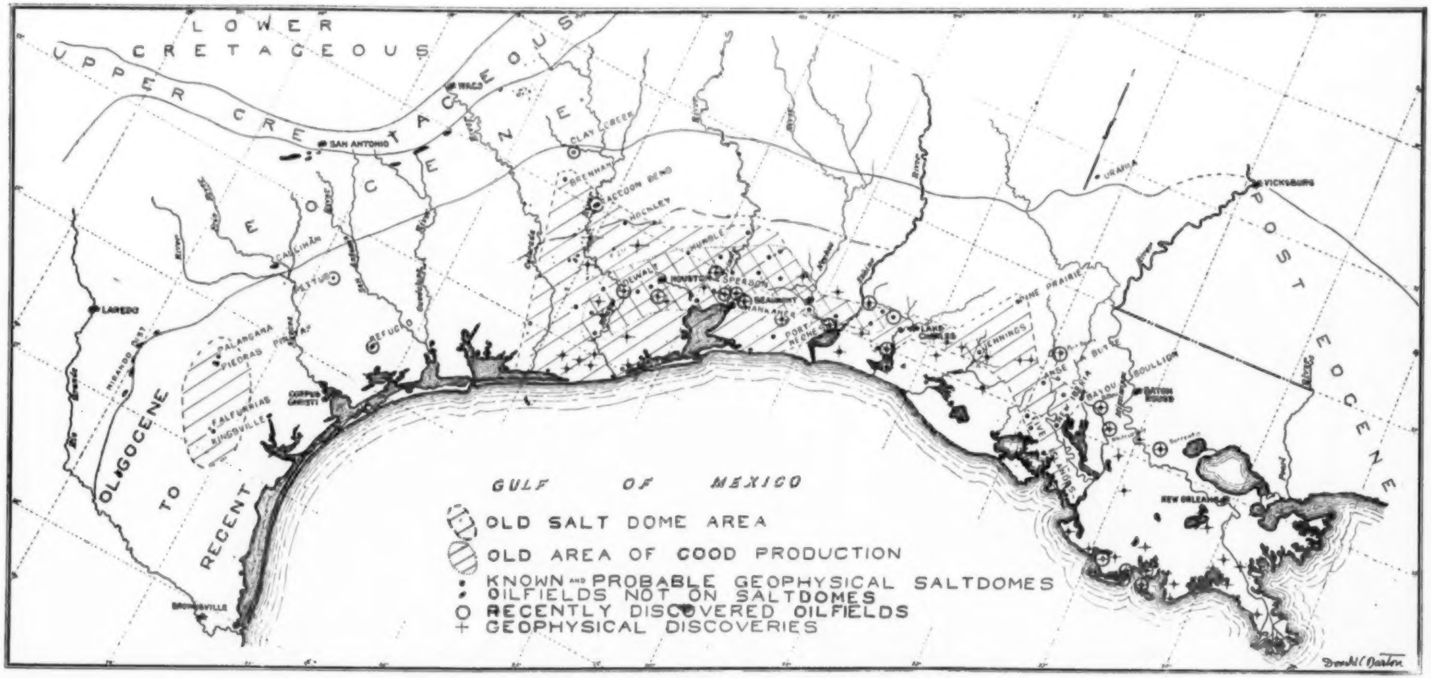

FIG. 1.—Sketch map of southern Texas and southern Louisiana.

The southwestern limit of good production has been pushed southwest at least to Refugio by the Refugio oil field and there is a good possibility that it may lie south of the Rio Grande. Formerly there was no good production southwest of the southwest edge of the "old" salt-dome area of southeast Texas. There was third-class production in the Laredo district and fourth-class production at Piedras Pintas, Three Rivers, and Kingsville; and south Texas was regarded as a gas province rather than an oil province. At the Refugio gas field, oil was discovered in 1928; during 1929, the production was increased to a total of 1,993,000 barrels; the possibilities of the field have not been fully explored; and the development of first-class production, possibly during the present year, seems probable. The gas production is mainly from the Miocene and the oil production is from the Oligocene. The deepest production is from a horizon which is regarded possibly as Fayette (Jackson.) The field lies in about the same geologic latitude with reference to the coast as the prolific production from the salt-dome oil fields of the "old" salt-dome area on the northeast. The scanty evidence available about the structure of the Refugio oil and gas field does not suggest association with a salt dome. The exploration of south Texas and of the whole coastal area southwest of the "old" salt-dome area has been slight. The establishment of good production at Refugio and Pettus (production from the Jackson) and the scattered small production at various stratigraphic horizons in the area farther south suggest strongly the possible extension of good production as far south as the Rio Grande.

The producing structures of the area south and southwest of the "old" salt-dome area may be predominantly non-salt-dome rather than salt-dome. Three salt domes, Palangana, Piedras Pintas, and Falfurrias. are known in the area of the Rio Grande embayment. Enough is known geologically and geophysically about the area to show that shallow salt domes are not present in as great numbers as they are in the "old" salt-dome area of southeast Texas. But, as there are three salt domes in the area of the Rio Grande embayment, the presence of more domes is to be expected, although the undiscovered domes may be deep.

Refugio is on a broad anticlinal arch, between the Rio Grande embayment and the "old" salt-dome area of southeast Texas, which is in the western part of the Mississippi embayment. In the area of this arch the salt may never have been deposited, or it may have been eroded, or the conditions of thrust may have been sufficiently different to prevent the formation of domes. Considerable geological evidence exists, there-

fore, for the expectation that no domes will be found in this intervening area.

The absence of salt domes should not preclude the presence of other types of petroliferous structure. The discovery of non-salt-dome structures will be much more difficult than the discovery of salt domes until the sensitivity of the geophysical methods is very greatly increased.

Inland, the area of good production has been extended into a zone in which there was practically no production. Formerly good production did not extend inland beyond the Humble, Batson, and Saratoga oil fields. Small amounts of oil had been found at Piedras Pintas, Brenham, and Pine Prairie, three of the four salt domes of the coastal group which are much farther inland than the others. Farther east in Louisiana there was the small Urania oil field, and farther southwest the third-class oil fields of the Laredo district. Raccoon Bend, a good field of the second class which was discovered 3 years ago, extended the area of good production slightly inland. The Clay Creek salt-dome oil field, discovered in 1928 much farther inland, produced 841,000 barrels during 1929 and, therefore, almost attained a second-class rating. As the field is controlled by one company and development is slower than it would be under competitive ownership, the field seems to deserve a potential rating of at least second class. The Clay Creek oil field, therefore, establishes the possibility of good production in a geologic zone in which there was previously no commercial production within 200 miles. With the small amount of oil on the Brenham salt dome, and with the good production at Raccoon Bend, there is suggestion of the continuous extension of good salt-dome production inland at least as far as the geologic latitude of Clay Creek. The presence of the Brenham and Clay Creek salt domes in that zone suggests the probable presence of other undiscovered salt domes. But the scarcity of clearly manifest surface indications of salt domes and the failure of considerable geophysical work to discover new domes suggests strongly, but does not definitely indicate, their rarity. Non-salt-dome types of structure are present in this zone; their connection with the occurrence of commercial oil fields remains a problem for the future to solve.

STRATIGRAPHIC EXTENSION OF GOOD PRODUCTION

The stratigraphic zone of potentially good production has been extended downward well into the Claiborne (Eocene). The production of 3 years ago came about 55 per cent from the Miocene, 35 per cent from the Oligocene, 5 per cent from the Jackson (upper Eocene), 5 per cent

from cap rock, and a small amount from the Claiborne (Middle Eocene). The Jackson production was good, but not prolific, minor production on a few domes. Most wells were abandoned at or above the top of the Jackson. Most wells which went into the Jackson did not go through the heaving shale which commonly is present in the Jackson.

The great potentialities of production from the Jackson, however, have been demonstrated by Raccoon Bend and by the new deep production at Humble. The production at Raccoon Bend is mainly from the Jackson; it is not prolific as compared with ordinary Gulf Coast production, but the producing area is large, and the production in 1929 amounted to 2,089,000 barrels. Deep production from the Jackson[1] was established during the year at Humble; the production is prolific; some of the wells were completed with an initial production of at least 5,000 barrels per day; and the total production from the Jackson at Humble during 1929 amounted to about 2,000,000 barrels.

The great potentialities of Cook Mountain–Mount Selman (Claiborne Eocene) production were demonstrated by the Clay Creek salt-dome oil field. Although not prolific as compared with Gulf Coast production, the production at Clay Creek is good for the shallow depth, 1,200 feet, and the total production for the year 1929 amounted to 841,000 barrels. The production extends down into the Wilcox (Lower Claiborne).

An enormously thick potentially productive stratigraphic section, therefore, is present in the seaward half of the Gulf Coast productive area. The Miocene, Oligocene, Jackson (upper Eocene), and Cook Mountain-Mount Selman (Middle and Lower Claiborne, middle Eocene) all afford prolific production, and small production is obtained from the Yegua (Upper Claiborne) and Wilcox (Lower Eocene). In the latitude of Houston in southeast Texas, the top of the Jackson lies at a depth of 5,000-5,500 feet on the upper flank of the Esperson dome, and dips rapidly; its depth at a distance from a salt dome must be at least 6,500 feet; the depth of the base of the Cook Mountain-Mount Selman must be at least 9,000 feet; and there is no reason to suspect that the thick Wilcox formation (Lower Eocene) underlying the Cook Mountain-Mount Selman is not potentially petroliferous. The results of reported seismic work and calculations based on torsion-balance surveys suggest that the unconsolidated sediments extend down to a depth of at least 15,000 feet. At the Jennings salt-dome oil field, the Yount Lee Oil Company's deep producer is only well into the Oligocene at 7,248 feet and the top of the Oligocene there normally must range from 1,000 to 2,000 feet deeper.

[1]By some paleontologists regarded as Upper Claiborne.

TABLE II

STRATIGRAPHIC DISTRIBUTION OF PRODUCTION IN OIL FIELDS OF GULF COAST AREA

Field	*Pliocene*	*Miocene*	*Oligocene*	*Eocene Claiborne*				*Age Unknown*
				Jackson	*Yegua*	*Cook Mountain-Mount Selman*	*Wilcox*	*Cap Rock*
SOUTH TEXAS								
Mirando district	–	–	–	O	t	t	....	....
Piedras Pintas	–	–	–	t	s	....	....	....
Kingsville	–	x	?NR	....	....	....	....	....
Refugio	–	gas	p	p	NR	....	....	....
SOUTHEAST TEXAS								
Clay Creek ‡	–	–	–	....	t	o	t	....
Brenham	–	–	–	....	....	t	NR	....
Big Hill (Matagorda County)	–	Untested		....	....	....	....	t
Markham	x	x	–	s	NR	....	....	....
Boling	–	–	x	....	NR	....	....	s
Big Creek	–	–	O	....	NR	....	....	t
Orchard*	–	–	–	x	–	NR	....	....
Raccoon Bend[1]	–	–	–	p	–	NR	....	....
Hockley	t	t	..	....	NR	....	....	t
Damon Mound	–	O	O	....	NR	....	....	–
West Columbia	t	p	O	t	....	....	NR	–
Nash*	–	x	t	t	NR	....	....	–
Allen*	–	t	–	–	NR	....	....	–
Stratton Ridge	–	t	NR	....	....	....	....	–
Hoskins Mound	–	Untested		....	....	....	....	t
Dewalt*	–	–	p	NR	....	....	....	....
Blue Ridge	t	O	O	t	t	....	NR	....
Pierce Junction	–	O	x	p	....	....	NR	–
Humble	s	p	p	p	s	t	NR	p
Mykawa*	–	–	?	....	....	....	....	....
Goose Creek[1]	t	p	p	NR	....	....	....	....
Barber's Hill	–	s	p	NR	....	....	....	–
Esperson*	–	x	t	t	NR	....	....	....
Hankamer*	–	x	..	....	....	....	....	....
Lost Lake*	–	–	s	....	....	....	....	–
Moss Bluff*	–	–	s	....	....	....	....	–
South Liberty-Dayton	s	t	p	s	t	NR	....	–
North Dayton	s	t	s	....	....	....	....	–
Sour Lake	t	p	p	O	x	....	NR	p
Hull	t	p	p	p	x	....	NR	–
Batson	t	p	..	....	NR	....	....	s
Saratoga	s	p	s	t	NR	....	....	....
Spindletop	–	p	p	....	NR	....	....	p
Fannett*	–	s	x	....	....	....	....	–
Big Hill (Jefferson County)	–	t	–	NR	....	....	....	....
High Island	–	s	NR	....	....	....	....	t
Port Neches*	–	o	..	....	....	....	....	....
Orange	s	p	p	NR	....	....	....	....

[1]Not yet shown to be a salt dome.

TABLE II—*Continued*

STRATIGRAPHIC DISTRIBUTION OF PRODUCTION IN OIL FIELDS OF GULF COAST AREA

Field	*Pliocene*	*Miocene*	*Oligocene*	*Eocene Claiborne*				*Age Unknown*
				Jackson	*Yegua*	*Cook Mountain-Mount Selman*	*Wilcox*	*Cap Rock*
SOUTH LOUISIANA								
Starks*	–	t	x	....	–	....	....	s
Vinton	–	p	t	–	NR	....	....	–
Black Bayou*	–	t	NR	....	NR	....	....	–
Sulphur	–	o	..	....	NR	....	....	–
Edgerly	s	p	NR	....	....	....	....	–
Lockport	..	p	NR	....	....	....	....	–
Hackberry	–	x	–	....	NR	....	....	–
East Hackberry*	–	o	t	....	NR	....	....	–
Sweet Lake	–	x	NR	....	....	....	....	....
Welsh	s	..	NR	....	....	....	....	....
Pine Prairie	–	t	..	....	NR	....	....	–
Jennings	s	p	o	NR	....	....	....	–
Port Barre*	–	–	s	s	....	....	....	....
Bayou Boullion	t	x	...	NR	....	....	....	–
Anse la Butte	s	x	s	NR	....	....	....	....
Bayou Bleu*	–	t	NR	....	....	....	....	–
White Castle*	–	t	NR	....	....	....	....	–
Sorrento*	–	–	NR	....	....	....	....	s
New Iberia	t	s	NR	....	....	....	....	–
Fausse Pointe*	–	–	NR	....	....	....	....	t
Dog Lake*	t	..	NR	....	....	....	....	–
Bay St. Elaine*	t	..	NR	....	....	....	....	–
Lake Barre*	–	x	NR	....	....	....	....	–
Lake Pelto*	–	s	NR	....	....	....	....	–
Caillon Island*	–	x	NR	....	....	....	....	–

Legend:

p = Prolific production
x = Fair production
t = Trace of production
* = Salt-dome discovery by geophysics
‡ = Recently discovered by geology
– = Dry
o = Good production
O = Recently discovered production
s = Small production
NR = Not reached

Eastward from Jennings, the Pliocene and Miocene are known to thicken greatly, and in the area of the Mississippi delta below New Orleans, the depth to the base of the Cook Mountain-Mount Selman can merely be guessed, and probably must be much greater than 10,000 feet. The favorable or unfavorable conditions of a formation for the occurrence of oil

may change as the formation dips gulfward, and such formations as the Cook Mountain and the Jackson may prove to be non-productive near the coast if they can be reached by the drill, but no reason is known now why they should not prove to be productive. Such a formation as the Wilcox may prove to be more favorable for the occurrence of oil where the formation has dipped to great depth. No final horizon has been found by drilling in the Gulf Coast area and, except for the increasing Baumé gravity of the oil with depth, there is no reason for expectation of the discovery of the final horizon by any drilling within the next decade.

EXTENSION OF ACTUAL DEPTH OF GOOD PRODUCTION

The actual, as well as the stratigraphic, depth of the production has been extended downward in the Gulf Coast area. Ten years ago most of the production came from depths of less than 4,000 feet. About 8 years ago, the deepest producer in the Gulf Coast area had a depth of 4,995 feet. Three years ago, the production at Sweet Lake, Louisiana, extended the maximum depth of production to 5,800 feet, but the total amount of production from below 5,000 feet in the Gulf Coast area was small. During 1929, prolific production was established between 5,200 and 5,500 feet both at Barber's Hill and Humble; the total production from depths greater than 5,000 feet amounted to more than 8,000,000 barrels; and the maximum depth of production was extended to 7,288 and 7,447 feet by the Yount Lee Oil Company's deep producers at Jennings, Louisiana.

DEEP SALT DOMES

The many deep domes which are being indicated by the torsion-balance and seismic surveys seem to offer enormous potentialities for production; the best of the "geophysical" oil fields lies on a deep salt dome, Dewalt, and many of the prospective deep domes lie between the prolific oil fields on the old shallow domes. The significance and importance of many of the reported prospective deep domes are in doubt and much disappointment may be experienced in exploration of the deep salt domes.

Three types of deep salt structures seem to be present: (1) deep salt domes in which the top of the salt is at a depth of approximately 4,000 feet, and in which the salt is detected fairly easily by the seismograph as well as by the torsion balance; (2) very deep domes in which the salt is detected by the torsion balance but in some domes not by the seismograph, and in which the top of the salt and cap probably lies at a greater depth than 7,000 feet (the seismograph somewhat commonly detects an irregularity in the fan shooting, and in profile shooting may be able to

map doming in the super-salt beds); and (3) salt ridges which as yet are known only from torsion-balance work, which are many miles in length, and in which the salt is probably at least 9,000 feet deep. The present classification of the salt domes as shallow, deep, and very deep domes is an arbitrary division for purposes of convenience; domes may be present with the top of the salt at any intermediate depths. Some of the domes are indicated as being crests on salt ridges.

TABLE III

KNOWN SALT DOMES WHICH HAVE BEEN MUCH DRILLED WITHOUT DISCOVERY OF OIL

	Number of Wells	
	SOUTH TEXAS	
Falfurrias		
Palangana	Many	
	SOUTHEAST TEXAS	
Hawkinsville	16	
Clemens	36	
Long Point	56	Trace of oil in cap
	SOUTH LOUISIANA	
Section 28	Many	
Jefferson Lake	14	

The deep, or "4,000-foot," type of dome is represented among the old domes by Edgerly and among the new geophysically discovered domes by Dewalt, Port Barre, Lost Lake, East Bay Junop, San Felipe, White Castle, and others. In the occurrence of oil, the deep domes should differ little from the shallow domes, except in the greater importance of super-cap production compared with flank production. The great potentialities of this type of dome are suggested by the Edgerly and Dewalt oil fields and by the small wells or showings obtained during 1929 at Port Barre, Lost Lake, East Bay Junop, and the poorer showings at San Felipe and Danbury. Edgerly, one of the old oil fields, is a poor second-class field. Dewalt is distinctly a good oil field, at least of high second-class rank and perhaps potentially of first-class rank. Although discovered only in 1928 and wholly controlled by the Humble Oil and Refining Company, Dewalt in 1929 produced almost 2,000,000 barrels of oil. Practically all the wells drilled at Dewalt have been producers.

The very deep type of dome is represented among the old domes by Orange and among the geophysically discovered domes, by Esperson, Hankamer, Port Neches, Mykawa, Genoa, Roanoke, Egan, Rosenberg, Iowa, Hayes, and many others. Theoretically, a dome of this type should be extremely favorable for the occurrence of prolific oil fields, provided that upthrust of the salt core has continued until somewhat

TABLE IV

KNOWN DOMES AND VERY PROBABLE PROSPECTIVE DOMES ON WHICH THERE HAS BEEN LITTLE OR NO DRILLING

	Geophysically Discovered Dome	*Presence of Dome Confirmed by Drilling*	*Number of Wells Drilled*
SOUTHEAST TEXAS			
Shepherds Mott	*	–	4
Sargent	*	–	0
Needville	*	–	2
Beasley	*	–	1
Rosenberg	*	–	0
San Felipe	*	*	8
East Stratton Ridge	*	–[1]	1
Danbury	*	*	5
Genoa	*	–	2
Cedar Bayou	*	–	2
Ogburne	*	–	1
Arriola	*	–	0
SOUTH LOUISIANA			
Cameron Meadows	*	–[2]	d
Calcasieu Lake	*	*	5
Iowa	*	–	0
Hays	*	–	0
Roanoke	*	–	4 Good showing of oil
Egan	*	–	1
Gueydan	*	–	0
Bayou Tortue	*	–	0
Abbeville	*	–	1
Avery Island	–	*	Many on top of dome
Weeks Island	–	*	Many on top of dome
Côte Blanche	–	*	Many on top of dome
Vermilion Bay	*	*	4
Belle Isle	–	*	Many on top of dome
Bayou de Glaise	*	*	3
Grosse Tête	*	*	0
Darrow	*	–	3
Napoleonville	*	*	3
Thibodaux	*	*	25 Mostly sulphur tests
East Bay Junop	*	*	2
Four Isle Bay	*	*	3
Leesville	*	–	d
Bay Marchand	*	–	d
Lake Hermitage	*	–	0
Potash	*	–	d
Bayou Long	*	*	3
Spanish Pass	*	–	d
Garden Island Bay	*	*	3
Bay St. Elaine	*	*	(Gas wells) 4
Lake Netherlands	*	–	0
Barataria	*	–	d

d = drilling * = Yes [1]Probably an extension of Stratton Ridge [2]Probably

TABLE V

LESS PROBABLE PROSPECTIVE SALT DOMES*
(DISCOVERED BY TORSION BALANCE OR SEISMOGRAPH)

*Many of these prospects are at localities where anomalies, mapped by the torsion balance or the seismograph or both, suggest but do not definitely indicate the presence of a salt dome.
The other prospects are those about which the writer has not been able to get reliable information.

		Wells Drilled
	COUNTIES IN TEXAS	
Fresno	Brazoria	1
Clodine	Fort Bend	2
Cheek	Jefferson	0
Devils Elbow	Brazoria	0
Eureka	Harris	1
Deer Park	Harris	1
Cove	Chambers	1
Francitas	Jackson	0
Hampshire	Liberty	1
La Belle	Jefferson	0
Manvel	Brazoria	1
Oyster Bayou	Chambers	d
Sandy Point	Brazoria	0
Satsuma	Harris	0
Devers	Liberty	1
	PARISHES IN LOUISIANA	
Bayou Cheney	St. Martin	0
Iota	Acadia	1
Lake Misere	Cameron	0
Mallard Bay	Cameron	1
Carencro	Lafayette	1
White Lake	Vermilion	0
Lake Bully Camp	LaFourche	0
Olivier	St. Bernard	0
Avoca	St. Mary	3
Wax Lake	St. Mary	d
Point au Fer	Terrebonne	1

d = drilling

recent geologic time and has domed the petroliferous zones sufficiently. The combination of the enormously thick, potentially productive stratigraphic section of the Gulf Coast area and moderate super-cap deformation above one of these very deep domes seems theoretically to have enormous potentialities for prolific production. The actual great potentialities of the very deep domes is demonstrated by the Orange oil field, which is now interpreted by geophysicists as a very deep salt dome. Orange is distinctly a first-class oil field; since the discovery of the main producing area in 1920, the total production has amounted to 29,000,000 barrels and the production for 1929 was 106,000,000 barrels. The discovery wells at Esperson, Hankamer, Port Neches, and Mykawa were completed only during the past year and exploration has not

been sufficient to justify a very definite judgment in regard to the potential grade of the oil fields present. The suggestion is strong that Esperson and Port Neches and possibly Hankamer ultimately will prove to be at least second-class oil fields. No opinion is justified in regard to the ultimate rank of Mykawa. These fields strongly resemble Orange in the indication of the great potentialities of these deep domes.

The number of the known and prospective very deep domes is large. Approximately 30 new prospective very deep domes were discovered geophysically during 1929. In Table II, five of the domes listed are very deep domes; in Table IV, twenty-five of the domes listed are very deep domes; and in Table V, each of the nineteen prospects is a very deep dome, if a dome.

The existence of some of those prospective domes is predicted on rather faint evidence, and some of them may not exist. Our knowledge of these very deep domes is scanty and there are faint anomalies in considerable number which conservative interpreters hesitate to interpret as domes, but which ultimately may prove in large part to reflect the presence of very deep salt domes.

Some of the very deep salt domes may be without structural expression in the upper part of the section; therefore, they may be dry in the present productive horizons. Uplift seems to have ceased at different times on different domes. Uplift has occurred on the Five Island domes, Damon Mound, Davis Hill, and Old Hackberry since late Pleistocene time, and possibly is continuing at present. No uplift has occurred at Big Creek, Boling, North Dayton, and Moss Bluff since some time within the Pleistocene. At Dewalt, according to oral communication from geologists of the Humble Oil and Refining Company, there has been little uplift since the beginning of Miocene time. The faint anomalies mapped by the seismograph on many of these deep domes suggest that the amount of upthrust of the salt since the beginning of Miocene time is slight. The upthrust of the salt may have ceased, for example, in Cook Mountain time on a dome; the post-Cook Mountain beds therefore would show no doming above the salt mass and would provide no structural trap for the accumulation of oil. The dome, therefore, would be dry within the limits of present-day drilling, and the presence of the dome could not be confirmed by drilling. But at greater depths such a dome would provide favorable structural conditions for the occurrence of oil deposits.

The salt ridges are known only from deduction from surveys with the torsion balance and from analogy with the German salt domes.

They are represented by long gravity minima, which look like linear equivalents of the subcircular minima of the known deep salt domes and of the roots of known shallow domes. The geological-geophysical interpretation of these minima suggests very strongly that they must be reflecting deeply buried salt ridges. These ridges, as far as the writer knows, have not been detected by the seismograph. The suggestion, therefore, is that the salt may be at very great depth and that appreciable doming of the super-salt beds may be lacking within 7,000 feet of the surface. Theoretically, the restriction of the formation of salt ridges to an early phase of salt-dome activity seems to be entirely possible, for example, to Eocene or earlier times and, if so, the post-Eocene beds would show no deformation. But the writer knows no reason for thinking that the formation of salt ridges necessarily is limited to the earlier phase of salt-dome activity.

The potentialities of the salt ridges are essentially unknown. Little probability seems to exist for important production from a depth less than 5,000 feet, and not enough is known about them to justify an estimate of their potentialities for production from greater depths. They are, however, distinct possibilities to be considered in connection with very deep production.

VARIATION IN OIL WITH ACTUAL AND WITH STRATIGRAPHIC DEPTH

A distinct tendency is shown in the Gulf Coast area for an increase of the Baumé gravity of the oil with increasing depth and in part with increasing stratigraphic depth. That tendency foreshadows a progressive change in the mean character of the oil of the future and gives the only suggestion, as yet, of a possible downward limit to production.

The very definite tendency toward an increase of gravity with depth of the producing sands is shown by Figure 2. The Baumé gravity is plotted against the depth of the producing sands for 223 wells at Orange, Hull, Sour Lake, Goose Creek, Humble, Orchard, Spindletop, High Island, Vinton, Sweet Lake, Piedras Pintas, Boling, South Liberty-Dayton, Brenham, and Clay Creek. Most of the determinations of the Baumé gravity are taken from commercial analyses made by the Sun Oil Company[1] and from the analyses published by the United States Bureau of Mines, and some are taken from commercial analyses by the Shell Petroleum Corporation[2] and from field determinations by the

[1]Through courtesy of R. W. Pack, Sun Oil Company.

[2]Through courtesy of geologic department, Shell Petroleum Corporation, Houston, Texas.

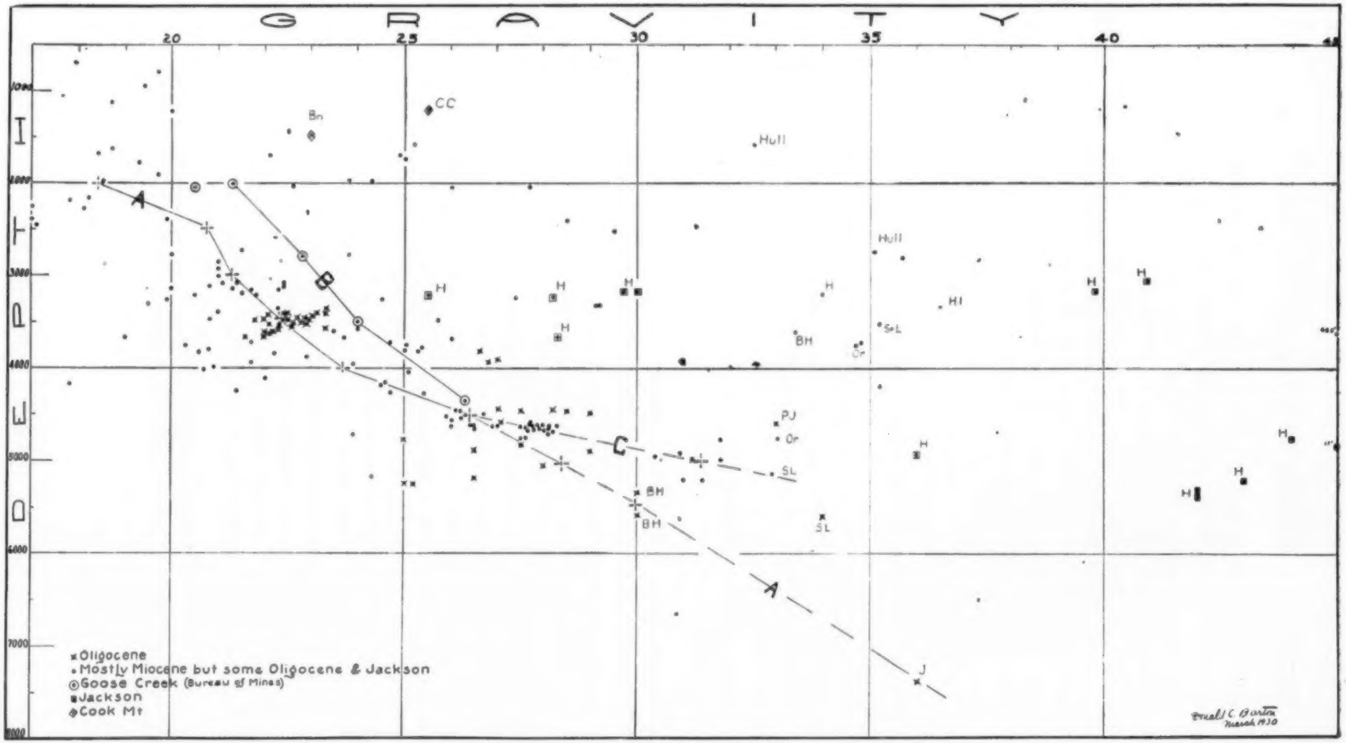

FIG. 2.—Variation of Baumé gravity with depth in Gulf Coast salt-dome area.

Bn.	Brenham	S. L.	South Liberty
C. C.	Clay Creek	Or.	Orange
H.	Humble	Sr. L.	Sour Lake
B. H.	Barbers Hill	H. I.	High Island
P. J.	Pierce Junction	J.	Jennings

The closely packed group of wells of Oligocene oil at 3,600 feet and 23° Baumé, is largely South Liberty. Most of the unlabeled samples are from Orange.

production of pipe-line departments. The general tendency toward an increase of gravity with depth is evident in spite of the very considerable variation. The increase of the median gravity at each 500-foot depth is shown by line *A*. The rate of increase is approximately 1° per 350 feet. The rate of increase at Goose Creek is shown by line *B*, which is based on four of the five analyses in a series published by the Bureau of Mines; the rate of increase is approximately 1° Bé. per 470 feet. An earlier study based chiefly on the Baumé gravity at Orange suggested an acceleration of the increase with depth as shown by line *C*. But the data from other fields and particularly from the Yount Lee Oil Company's deep well at Jennings suggest an approximately linear rate of increase.

A stratigraphic variation in the Baumé gravity is shown between the Eocene and the Miocene-Oligocene oil, but not between the Miocene and the Oligocene oil. The position of the Miocene-Oligocene oils on the graph seems to be determined by depth and not by the stratigraphic age of the producing horizon. The position of the Eocene oils on the graph is consistently at the right of that of the main mass of the Miocene and Oligocene oils and the mean shift is about 4° Bé. at 1,500 feet, 6° at 3,000 feet, and 13° at 5,000 feet. Not enough analyses were available to permit a dependable determination of the rate of increase with depth for the Eocene oil.

An increasing content of the gasoline fractions and a decreasing content of the lubricating fractions tend to accompany the increasing Baumé gravity. The characteristic Gulf Coast crude of a decade ago was produced from Miocene or Oligocene sands at a depth of less than 4,000 feet and was characterized by a high content of lubricating stock and the practical absence of gasoline. The Miocene-Oligocene oils now being produced from below 4,000-4,500 feet at Orange tend to have a gasoline content of 11-14 per cent. The Jackson (Eocene) oils characteristically have a considerable gasoline content, those from Humble, 22 per cent.

The production of the future will tend to come more and more from deeper and deeper Miocene or Oligocene sands and from Eocene sands. The tendency for an increase in the mean Baumé gravity of the Gulf Coast crude produced each year has been manifest for 5 years or more and will continue. The character of most of the crude produced each year will change from that of the characteristic Gulf Coast "A" lubricating stock crude toward crudes more like the Mid-Continent crudes. In the future the Gulf Coast crudes, therefore, will have to compete increasingly with the Mid-Continent crudes.

The increase in gravity with depth suggests an ultimate downward limit to production. If a straight-line variation for the Miocene-Oligocene continues to great depth at a rate of 1° Bé. per 350-400 feet, a Baumé gravity of 50° will not be reached above 12,000-13,000 feet in depth. But in the Eocene a Baumé gravity of 50° would be reached at 9,000-10,000 feet. The critical depth should be shallower toward the inner part of the Gulf Coast area and deeper toward the coast. Production from below the critical depth might consist of very wet gas.

ESTIMATED RESERVES OF GULF COAST AREA

For the shallow domes of the "old" salt-dome area of southeast Texas and southwest Louisiana, the 1921 and 1928 estimates respectively of 2,100,000,000 and 2,300,000,000 (±40 per cent) barrels seem essentially correct, although probably slightly conservative in the light of the prolific character of the downward extension of production. The reserves of those estimates were envisaged as lying mostly on the known domes and on expected but at that time undiscovered domes in essentially the area in which the known domes lay. The deep domes were not foreseen. The expected new (shallow) salt domes have been discovered. Since January 1, 1921, 377,000,000 barrels of oil have been produced, amounting to almost one-fifth of the reserves of the 1921 estimate. The time necessary to produce the other four-fifths will be 35 years if production continues at the rate of production for the past few years. The mounting rate of annual production shown on Figure 3, the number of new oil fields which are being discovered, the development of good production on salt-dome oil fields condemned as third-rate or nearly exhausted, the considerable number of shallow domes still relatively untested, for example, Big Hill, Matagorda, Bryan Heights, Stratton Ridge, and Hoskins Mound, justify conservatively the belief that shallow salt domes of the "old" salt-dome area with the old deep salt-dome oil fields, Edgerly, Orange, and Goose Creek, will have produced oil to the amount of that remaining four-fifths of the 1921 estimate by the end of the next 30 years and will still be producing plentifully. The results of the exploration of the Miocene producing horizons during the recent past has been perhaps slightly below the expectations of those estimates, of the Oligocene slightly above those expectations, of the Jackson above expectations, of increasing depths fully up to expectations. As both sets of estimates were carefully made and as subsequent development suggests that they were slightly too conservative, the estimate seems justified that the productive reserves on the shallow salt domes

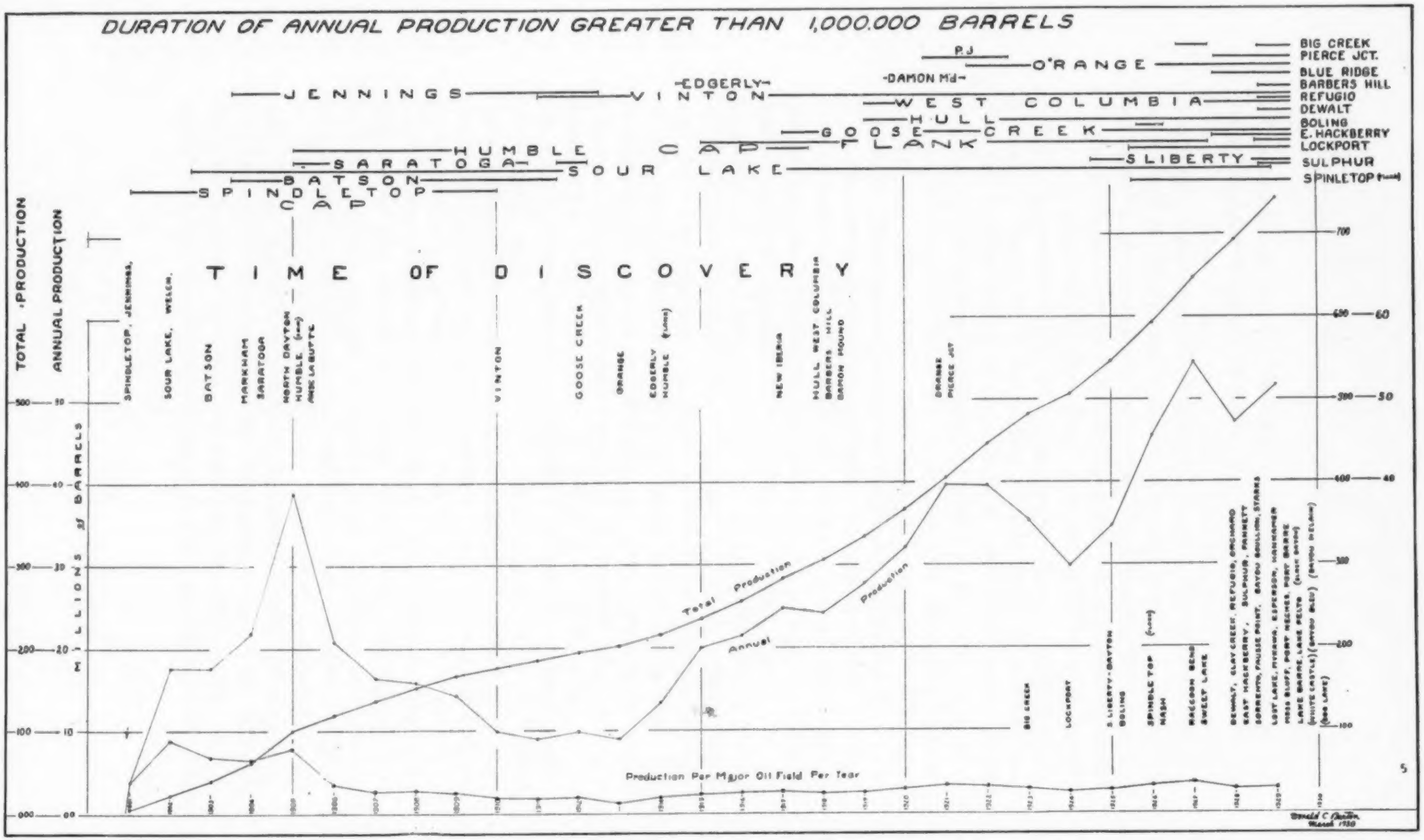

FIG. 3.—Production curves, time of discovery of production, and duration of annual production greater than 1,000,000 barrels in the Gulf Coast coastal oil fields. (Mirando district, Calliham omitted.)

of the old salt-dome area will amount surely to at least 2,000,000,000 barrels, probably to 2,500,000,000 barrels, and possibly to 3,000,000,000 barrels.

The probable accuracy of this estimate is much superior to that of the remainder of the estimates to follow. All of the shallow domes within the old salt-dome area seem probably to have been discovered, although there is a bare possibility of the discovery of a shallow dome or two of small diameter and of a depth of 1,500-2,500 feet.

For the newly extended area of possible shallow domes east of New Iberia and north of the Humble and Brenham salt domes, and for the deep and very deep domes of those areas as well as of the "old" salt-dome area, only a far less accurate guess can be made of the probably recoverable reserves.

Far less is known of the potentialities of those areas and types of domes. But the 28 or more "geophysical" salt domes already discovered east of Lafayette with small amounts of oil already discovered on 10 of the domes, the 30 or more deep or very deep domes discovered or strongly indicated by geophysical prospecting, the Dewalt, Port Neches, Esperson, and Hankamer oil fields on those domes, the salt-dome ridges, and the good salt-dome production at Clay Creek justify the expectation of additional undiscovered potential production in the same zone, and suggest: (1) reasonable certainty of effective reserves equal to at least half those of the shallow domes of the "old" salt-dome area, that is, about 1,000,000,000 barrels; (2) probability, at least, of effective reserves almost as great as those of the shallow domes of the "old" salt-dome area, that is, about 2,000,000,000 barrels; and (3) possibility of much larger effective reserves, that is, perhaps as much as 4,000,000,000 barrels.

The probability of the first two figures seems good. With the demonstrated character of the old oil fields, Orange and Sour Lake, with the behavior of the new oil fields, Dewalt, Port Neches, Esperson, Hankamer, Clay Creek, and Raccoon Bend, the writer can not picture any combination of conditions such that the ultimate production will be less than 1,000,000,000 barrels and it is difficult for his imagination to picture conditions such that the ultimate production will not be at least 2,000,000,000 barrels.

The probability of the last figure is not as good as the corresponding figure for the shallow domes of the "old" salt-dome area. The writer can easily imagine conditions such that it is much too conservative. The number of the deep and very deep salt domes is not known. New domes

are being reported at close intervals. The full degree of production can not be gauged now. The potentialities of the salt ridges are totally unknown. The potentialities of possible non-salt-dome structures in the Clay Creek zone of the Gulf Coast area are totally unknown. The deep and very deep domes, the shallow domes of the extended salt-dome areas, possible non-salt-dome structures, together seem to have possibilities, at least, slightly greater than the shallow domes of the "old" salt-dome area; therefore, the figure of 4,000,000,000 barrels seems justified in comparison with the figure of 3,000,000,000 barrels for the shallow domes of the "old" salt-dome area. But at present there is no way of forecasting how much greater those possibilities will prove ultimately to be.

For the area southwestward from the "old" salt-dome area of southeast Texas past Refugio to the Rio Grande, any estimate of reserves is a mere guess. The behavior of the Refugio oil field during the past year, the scattered small oil fields farther south, the vast extent of country which has been very slightly explored with the drill, and the close correspondence of the formations with those of the prolifically productive area adjacent on the northeast, all suggest considerable reserves surely equal to a quarter, probably equal to a half, and possibly equal to the whole of the potentially productive reserves of the shallow domes of the "old" salt-dome area of southeast Texas and southwest Louisiana; that is: surely, at least 500,000,000 barrels; probably, at least 1,000,000,000 barrels; possibly, at least 3,000,000,000 barrels.

The probable accuracy of the last figure is the poorest of any of the figures of these estimates. The area of south Texas is vast and there has been comparatively little exploration of it with the drill. The prolifically productive horizons of southeast Texas may become progressively less productive as they grade into the corresponding horizon of south Texas, but, on the contrary, they may not, and it is easy to picture conditions such that the ultimate production of south Texas will far exceed 3,000,000,000 barrels.

The general magnitude of the effective potentially productive reserves of the Gulf Coast area, therefore, is: surely, at least 3,500,000,000 barrels; probably, at least 5,500,000,000 barrels; and possibly, at least 10,000,000,000 barrels.

This estimate is based on an attempted shrewd guess of probable potential future production similar to that of the oil fields already known in the Gulf Coast area. The estimated reserves, therefore, consist of oil which can be produced by essentially the present methods of production at a price of crude oil within the range of prices of the past decade. The

present efficiency of the extraction of oil from most oil sands commonly is believed by oil geologists to be between 20 and 40 per cent, and 80-60 per cent of the oil originally present is believed to be left in the oil sand. There is a reasonable possibility, therefore, of an unrecoverable reserve at least as large, and possibly twice as large, as the recoverable reserve. The unit operation of oil pools, control of the gas-oil ratio, re-pressuring, and artificial flood are attempts to increase the efficiency of the extraction and to recover part of the hitherto unrecoverable oil. What ultimate success will be obtained in the application of such methods in the Gulf Coast area, it is impossible to predict.

In the estimates made in this paper, an allowance has been made for a progressive slight increase in the efficiency of the extraction of oil in the Gulf Coast area; there is a reasonable possibility that the increase in that efficiency will be considerably larger and that the potentially productive reserves will be increased correspondingly. If the price of crude should rise considerably above the prices which have prevailed in the immediate past, the development and application of more efficient methods of extraction will be accelerated and will be carried further than if there had been no considerable increase in the price of crude. There is, therefore, this additional possibility that the productive reserves will prove ultimately to be larger than those of the present estimate.

SALT FLAT OIL FIELD, CALDWELL COUNTY, TEXAS[1]

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ABSTRACT

The Salt Flat oil field in southern Caldwell County, Texas, was opened October 13, 1928, making the third oil field in Caldwell County producing from the Edwards limestone. A daily peak of 52,013 barrels was reached on June 18, 1929. In all, 343 wells have been drilled, only 25 of which are dry holes.

The Salt Flat field is located parallel with, and on the southeast or upthrown side of, a fault which strikes N. 30° E. The fault has a maximum vertical displacement of 375 feet.

The pay formation is the upper 25-35 feet of the Edwards limestone (Comanche), which is a porous dolomitic limestone with lenses of indurated cherty limestone. The upper few feet of the pay formation is ordinarily soft yellowish limestone, commonly referred to as "dobe." A few wells have encountered commercial production above the Edwards limestone. The surface beds in the Salt Flat field are Wilcox sand and shale, which are Eocene or early Tertiary in age.

The Salt Flat field, which consists of 1,196 productive acres, produced 13,790,362 barrels of 36° gravity oil (A. P. I.) to the end of 1929. It is estimated that the ultimate recovery will be approximately 30,000 barrels per acre, or a total recovery of approximately 36,000,000 barrels of oil for the entire field.

The average depth to the pay horizon is 2,700 feet, and rotary methods of drilling have been used exclusively. Most of the wells are pumped with individual electric pumping units.

INTRODUCTION

The Salt Flat (Bruner) field is an excellent example of an accumulation of oil in the Edwards limestone on the upthrown side of a normal fault. The field extends along a fault with a northeast-southwest trend, for a distance of approximately 6 miles.

The Salt Flat field derived its name from a salt marsh, or flat, near the southwest end of the field, where the first drilling took place. The occurrence and location of the salt marsh are probably associated in some way with the faulting in the Salt Flat field. The field is located in southern Caldwell County, northeast of the town of Luling, and is situated in the region of early Tertiary beds, approximately 4.5 miles southeast of the Luling oil field,[3] or 40 miles south of Austin, Texas. It is com-

[1]Read before the Association at the New Orleans meeting, March 20, 1930. Manuscript received by the editor, June 9, 1930.

[2]Geologists, Humble Oil and Refining Company.

[3]Ernest W. Brucks, "The Luling Field, Caldwell and Guadalupe Counties, Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 9, No. 3 (May-June, 1925), pp. 632-54.

parable with the Luling oil field in that both faults are normal faults with the upthrown side on the southeast; each has Wilcox beds exposed at the surface; and each produces from the Edwards limestone. The Salt Flat field differs largely from the Luling oil field in that the fault has less vertical displacement, the productive area is less, and it is approximately 650 feet lower structurally. The country surrounding the Salt Flat field varies from gently rolling, slightly wooded areas in the southwest part, to stream-valley agricultural land in the northeast part. Plum Creek, which flows southwest into San Marcos River, controls the drainage of this area. The field is served by good gravel roads extending northeast from the town of Luling.

The writers wish to acknowledge their indebtedness to L. T. Barrow for his helpful suggestions and encouragement in preparing this paper, and to the other officials of the Humble Oil and Refining Company for their permission to publish it. The writers also wish to express their appreciation to W. A. Maley, who was field geologist for this company during the early development of the Salt Flat field, to F. W. Rolshausen of the company laboratory, to R. G. Gerber of the company engineering department, who drafted the accompanying maps and figures, and to the other companies and geologists who have contributed information used in this paper.

HISTORY

Subsequent to the discovery of the old Luling field,[1] in 1922, an active geologic, lease, and drilling campaign was carried on along the fault line, in search of additional Edwards limestone fields. Prior to the discovery of the Salt Flat field, approximately 175 tests were drilled within the vicinity of Caldwell County alone, in search of additional Edwards limestone fields. The results obtained were discouraging with the exception of the discovery of one small pool near Larremore,[2] in the vicinity of Lockhart, Caldwell County, Texas, in which there were only ten producing wells.

On April 9, 1927, Sullivan *et al.* began their Davis No. 1, which was later acquired by Bruner *et al.*, and completed as a small producer from the Austin chalk on May 28, 1928. On June 25, 1929, the Luling Oil and Gas Company's Carter No. 1 had a showing of oil in the Austin chalk, at which depth it was abandoned. The Luling Oil and Gas Company's Carter No. 2 had about the same showing in the Austin chalk as Carter

[1] Ernest W. Brucks, *op. cit.*

[2] A. W. Weeks, "Geology of Larremore Area, Caldwell County, Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 14, No. 7 (July, 1930), pp. 917-22.

No. 1, and was drilled into the Edwards limestone with only a slight showing of oil. The Ratcliff *et al.* New No. 1 was drilled into the Edwards limestone on September 1, 1928, and had a showing of oil.

Subsequent to the discovery of oil in the Austin chalk in the Sullivan *et al.* (Bruner) Davis No. 1, the Golden West Oil Company completed their Malone No. 1 as a 500-barrel producer from the same horizon. Immediately afterward several other wells were begun near this well, all of which were in the vicinity of the salt marsh. The Sun Oil Company's Malone No. 1 was drilled to the Austin chalk in search of the same production which was encountered in the Golden West Malone No. 1, but had only a slight showing of oil in the Austin chalk. This well was then drilled to the Edwards limestone, and resulted in the discovery of the Salt Flat field on October 13, 1928.

Due to the small size of the leases in this field, drilling activity progressed very rapidly, with a maximum of forty rigs being used at one time, resulting in a peak of 52,013 barrels on June 18, 1929. The activity gradually decreased from that date, until to-day there are only two rigs running in the Salt Flat field.

It is interesting to notice that out of a total of 343 wells drilled in the Salt Flat field only 25 were dry holes. Many of the dry holes were drilled prior to the discovery of the field.

The uniform porosity of the Edwards limestone is such that every well which penetrated the top of the formation between −2,250 and −2,330 feet made a producer, there being not a single "tight-lime" dry hole in the entire field.

STRATIGRAPHY

The purpose of this section is to discuss the formations which are actually penetrated by the drill in the Salt Flat field and to discuss the surface geology immediately adjacent to the field. The writers feel that the areal geology of this region, together with surface exposures of the beds penetrated in the Salt Flat field, have been discussed sufficiently by the several authors whose published works may be consulted for additional information. The writers have, therefore, confined the descriptions of the formations encountered in the field largely to their actual appearance and characteristics as noticed from cores, cuttings, and well logs.

Wells drilled in the Salt Flat field penetrate the formations shown in Figure 1. Most of the wells begin near the upper part of the middle sand member of the Indio formation and find the pay horizon in the top

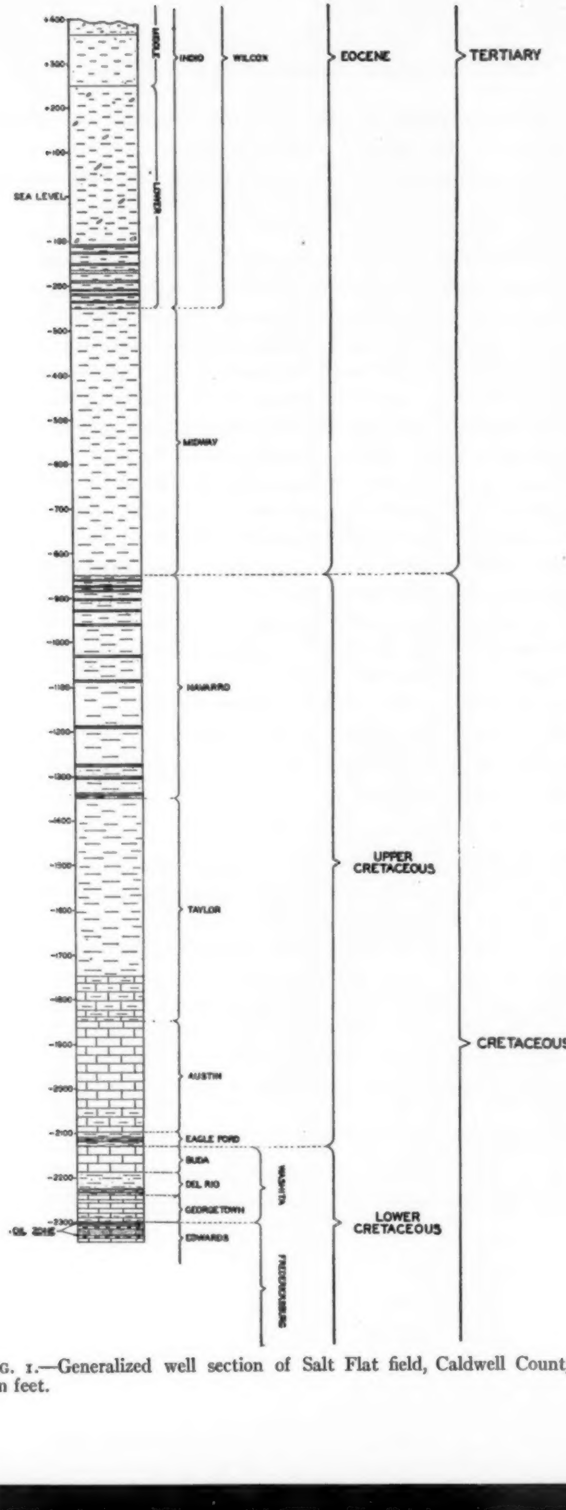


FIG. 1.—Generalized well section of Salt Flat field, Caldwell County, Texas. Scale in feet.

of the Edwards limestone. The average depth of the pay horizon is approximately 2,700 feet.

TERTIARY

Indio.—At the surface there is ordinarily 30-40 feet of sand and gravel, or finely divided alluvial soil. After this has been passed through, the drill penetrates 100-200 feet of sand or goes directly into the lower shale member of the Indio. This variance is due either to elevation or to the proximity of some of the wells to the surface fault, as the middle sand member of the Indio is normally about 200 feet in thickness.

The Lower Indio is composed of variegated sandy shales containing lignitic material. These shales also carry a few concretionary boulders of siliceous material, which have a blue-gray color when freshly broken. In some areas, sandstone strata are present near the base of these shales, interstratified with the sandy shale and lignitic material. This material comprises a section possibly 50 feet thick.

The Indio beds are logged by the driller as "shale and boulders" and are the cause of much delay in drilling operations on account of the lenticular shape and the extreme hardness of the boulders. The Indio in general is considered as non-marine sediment. In some local outcrops, however, the sandstone and sandstone concretions contain fossil shark teeth, plant stems, and oyster shells. There is approximately 700 feet of the Indio deposits in the Salt Flat field.

Midway.—After the drill has passed through the Indio, it enters an unctuous calcareous clay containing some quartz and glauconitic sand. The average thickness of this section is approximately 600 feet. These rather uniform beds comprise the Midway formation and are of marine origin, as revealed by the plentiful foraminifers and fragmentary pelecypods and gastropods encountered in the well cuttings. The macroscopic fossils are especially plentiful near the base of these beds. The most plentiful of these is *Venericardia*. Within this basal horizon there is much glauconitic sand. This seems to be due to an unconformity at the top of the underlying formation which gave rise to near-shore or shallow-water conditions as the Navarro land mass was submerged into the Midway seas.

This formation drills very slowly, as it contains much argillaceous material. It is invariably logged by the drillers as "sticky shale."

UPPER CRETACEOUS

Navarro.—From the point where the drill passes from the Midway formation to a point near the top of the Austin chalk, sediments of much

the same character are encountered, namely, massively stratified marls. Much more sand occurs in the upper half of the Navarro formation than in other parts of the marl section. This part of the Navarro contains strata of blue-gray fine-grained sandstone some of which are as much as 12 inches in thickness and are interstratified with sandy shale and gray marl, the latter constituent being predominant. The total thickness of the Navarro formation in this area is approximately 500 feet. The lower half of the Navarro is principally a gray marl. As seen from plentiful fossil remains of both macroscopic and microscopic marine forms of life, this formation, like the marl formations below and above it, is of shallow epi-continental marine origin.

Taylor.—The Taylor is more typically a marl formation. It is an unctuous clay approximately 500 feet in thickness, containing a large amount of calcium carbonate. Due to the calcium carbonate and pyrite, it is rather difficult to drill. These characteristics give rise to the driller's term "hard, sticky shale." It has been observed that more pyrite is ordinarily logged when the drill nears a fault plane. The upper 300 or 400 feet of the Taylor marl is uniform, stratification marks not ordinarily being perceptible until weathering has begun. The lower 100-150 feet of the Taylor section is composed of thick beds of chalky marl separated by shale and softer marl beds, and is commonly termed the Taylor chalk. In drilling, this material may appear in the cuttings like the Austin chalk material beneath it, and the behavior of the drill suggests Austin chalk. Also, after penetrating 40 feet of this material, a 15 or 20-foot shale or marl bed is reached, which in some places has caused the drillers to log erroneously a short section of Austin chalk with a normal section of Eagle Ford beneath it.

Austin.—In many places at the top of the Austin chalk a 5-10-foot bed of soft chalk is encountered which contains showings of oil. Some of the first wells drilled were completed in this horizon as small producers. Many wells in the field showed considerable oil from this horizon, while they were being drilled, thereby causing the operators much keen interest. Most of the wells tested, however, proved to be disappointing.

Cuttings from this horizon commonly come to the surface as soft buff oil-stained chalk. Beneath this horizon, the Austin chalk is composed of uniformly thick beds of white, fairly soft, somewhat brittle limestone containing specks of glauconitic material. These beds ordinarily are separated by thin gray shaly marl partings, which in some places become much thicker near the base of the Austin chalk section.

This is a truly marine formation, as shown by the character of the sediment and type of microscopic life seen in the cuttings.

Eagle Ford.—Beneath the Austin chalk there is ordinarily 30 feet of sandy lignitic shale containing dark sandy limestone with lignitic and bentonitic strata near the middle. These beds commonly carry oyster shells, shark teeth, and fish scales. When the Eagle Ford sediments are encountered with the drill, the cuttings show dark speckled shale and in places much lignitic wood. The drilling fluid, or slush, commonly darkens immediately after the Eagle Ford shale has been penetrated.

The character of the sediment and the fossil content of this formation indicate shallow-sea conditions during the time in which the deposition took place.

LOWER CRETACEOUS

Buda.—The Buda limestone has an average thickness of 60 feet in the Salt Flat field. It is composed of homogeneous, hard, grayish white limestone material. On very close examination, small calcite-filled fractures or thin calcitized shell fragments are noticed and the limestone matrix has a dense lithographic appearance. The hardness of the Buda limestone, its lithographic density, and its sharp square-cornered manner of fracturing distinguishes it from the Austin chalk, which it resembles closely in color. The Buda is of marine origin.

When outcrops of the Buda and Eagle Ford are studied, it is found that there is a slight unconformity between the two formations.

Del Rio.—The Del Rio clay directly underlies the Buda limestone and is composed of a greenish or blue-black clay in its upper 40 feet. Similar material occurs in the lower 10 feet of the section, interstratified with several layers of hard gray sandy limestone ranging from 3 to 10 inches in thickness and in many places carrying plentiful *Exogyra arietina*.

The Del Rio clay can be drilled only very slowly on account of its stiff, sticky character and is logged as "gumbo" by most drillers. The lower 10 feet, where the sandy limestone strata are encountered, may be mistaken for the Georgetown limestone beneath it.

This formation is of shallow marine origin, as shown by the character of the sediment and content of microscopic and larger fossils.

Georgetown.—The Georgetown limestone is composed of 60 feet of blue-gray limestone which is interstratified with a few layers of blue shale or clay and fossiliferous horizons. Fossils commonly seen in cores from the basal Georgetown, where thin shale partings are fairly plentiful, are *Gryphaea* and *Ostrea*, particularly *Alectryonia carinata*.

In drilling operations it is especially important that the top of the Georgetown limestone be definitely known, inasmuch as the common

practice is to set and cement casing as close to the base of the Georgetown as possible before drilling into the Edwards. At first the operators had some difficulty in determining the top of the Georgetown, as the hard strata in the basal Del Rio were misleading. It was ultimately ascertained, however, that the top of the Georgetown was not penetrated until the drill showed solid drilling in fairly hard limestone. When this condition was obtained, it was commonly noticed that cuttings of a light blue flakey limestone soon appeared in the slush with blue-gray limestone cuttings, the latter gradually increasing. In almost all wells where this marker was used as the top of the Georgetown, 55-60 feet was drilled before encountering the Edwards limestone.

Most parts of the Georgetown formation drill as a hard limestone, and this causes the bit to hang and jump slightly. This is particularly true of those wells located as "downthrow" wells or where the wells are very near the fault plane in the Georgetown. The latter condition is due to much pyrite, possibly caused by solutions of the material having been filtered into the formations near the fractured zone.

Edwards.—The Edwards formation is composed of limestone, parts of which are dolomitic and cherty. Beds of pure flint and flint nodules as large as 10 inches thick occur in its upper parts.

The top of the Edwards in the Salt Flat field is marked by a change from the hard drilling of the Georgetown to the extremely soft drilling encountered in the upper 2-3 feet of "rotten" dolomitic limestone which is the top bed of the formation here discussed. This material contains good oil showings, and, when examined closely, is seen to resemble soft yellow oil-saturated powder composed of almost microscopic particles of dolomite and chalk.

Beneath this "dobe" material, as the drillers commonly call it, there is an 8-10-foot section of soft dolomitic porous oil-saturated limestone which commonly overlies a 6 or 8-inch extremely hard concretionary flint layer. This hard zone is not encountered in some of the wells. It is present in most of them, however, so that it seems to be either lenticular or concretionary.

Beneath this flint horizon there is a 15-20-foot section of very soft, porous, oil-saturated dolomitic limestone, which ordinarily overlies a zone of material thought to be composed of concretionary flint. This section of the pay horizon is evidently the more porous, or the more productive of the two.

In some places where the hard stratum near the base of the pay formation is broken or drilled through, salt and sulphur water are en-

FIG. 2.—Exposure of upper Edwards limestone, 1 mile southwest of Barton Springs, Travis County, Texas.

countered and if not "plugged back" the oil well is damaged. This is true only of wells located on the east edge of the field, where the water-oil contact happens to coincide with the concretionary flint zone. In some wells which are abnormally high structurally, the pay horizon extends deeper than 30 feet from the top of the "dobe," and pay formation is encountered beneath the lower flint zone.

The following are analyses of two representative samples of Edwards limestone from Salt Flat wells.[1]

HUMBLE OIL AND REFINING COMPANY'S JOHNSON NO. 2

Sample No. 1,534
Depth, 2,666-77.5 feet
Insoluble material, 2.3 per cent
Calcium carbonate, 83.3 per cent
Magnesium carbonate, 11.1 per cent
Organic material, moisture, etc., 3.3 per cent
Remarks: Ground-up lime ("dobe" sample)

HUMBLE OIL AND REFINING COMPANY'S DAVIS NO. 2

Sample No. 15,045
Depth, 2,700-02
Insoluble material, 3.2 per cent
Calcium carbonate, 44.2 per cent
Magnesium carbonate, 32.0 per cent
Organic material, moisture, etc., 20.6 per cent
Remarks: Tan dolomitic limestone (sample below the "dobe")

[1]Analyses by F. W. Rolshausen, Humble Oil and Refining Company Laboratory, Houston, Texas.

SURFACE GEOLOGY

The strike of the strata in the vicinity of the Salt Flat field is N. 30° E., or approximately parallel with the strike of the Balcones fault. The dip of the beds is southeast at the rate of approximately 2°. The surface exposures in the field are middle and upper Wilcox of Eocene age. Stream material and Pleistocene gravel have concealed most of the beds within the field, there being only here and there an exposure of material *in situ* in some of the small streams. The streams and stream valleys in and adjacent to the field, like most streams and stream valleys within the Wilcox outcrop, have concealed most of the good exposures with detrital material.

Due to the extensive mantle of alluvial and Pleistocene material, no exposures of the major faulting are present. One exposure of a fault plane which strikes N. 35° W. is present on the west side of the road, near the Morgan Brothers' Malone lease, which is on the south side of a small cemetery.

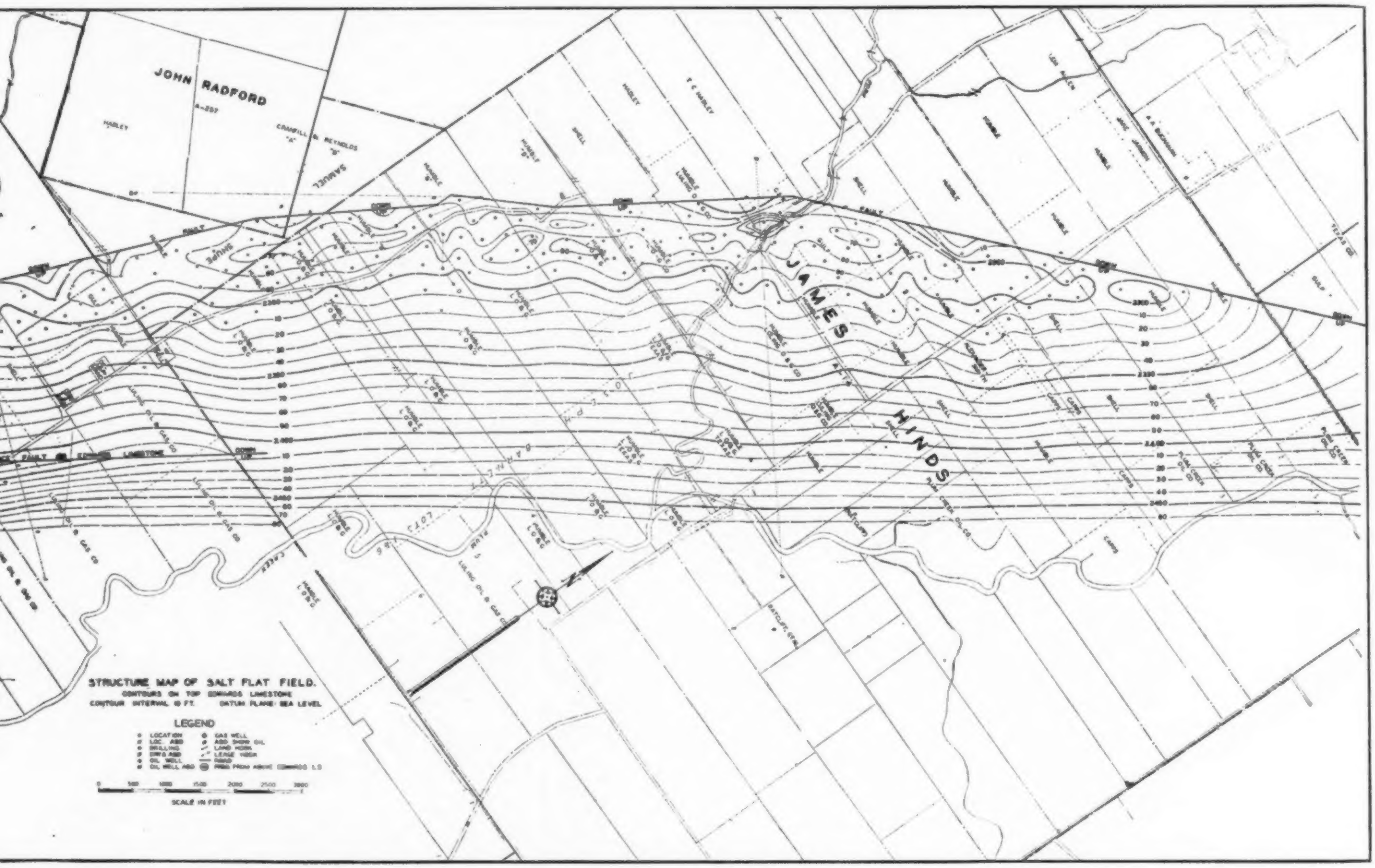
The Wilcox beds are underlain by Midway shales of Eocene age which crop out about 10 miles northwest of the Salt Flat field. The Wilcox is overlain by Carrizo sand, also of Eocene age, which crops out about 5 miles southeast of the field, and gives rise to the band of hills which stand out in striking contrast to the surrounding flat country. Largely as a result of the faulting in this vicinity, the Wilcox-Carrizo contact makes a large, gentle down-dip swing away from the field.

The lithologic character of the Wilcox deposits is such that ordinarily a field geologist finds it rather difficult and generally impossible to correlate or map individual beds in order to decipher local structure. As a result many local dips are mapped which, due to a preponderance of cross-bedding within the Wilcox, prove worthless and leave the geologist unable to interpret the local structure. It is ordinarily found that general zones can be mapped within the Wilcox outcrop which help in deciphering the structural conditions.

As has been stated previously, most of the beds in the Salt Flat field have been hidden by a mantle of alluvial and Pleistocene material. It is obvious, however, from the exposures which may be found, that beds on either side of the field do not occur in the same part of the Wilcox section. In other words, exposures on the east side of the field belong to a part of the Wilcox section which is stratigraphically below the beds which occur within and west of the field. The fault plane or exact contact of these beds is hidden by the alluvial covering.


FLOYD
A-102
J. TYLER
PETER NORTON
GERRON
HINDS
SPENCER MORRIS
A-15

PLATE 4


STRUCTURE MAP OF SALT FLAT FIELD.
CONTOURS ON TOP EDWARDS LIMESTONE
CONTOUR INTERVAL 10 FT.
DATUM PLANE: SEA LEVEL
LEGEND
LOCATION
GAS WELL
LOC. ABD
DRILLING
LAND HOOK
LEASE HOOK
OIL WELL
ROAD
OIL WELL ABD
0
1500
2000
2500
3000
SCALE IN FEET
JOHN RADFORD
SAMUEL
JAMES
HINDS

The southwest end of the field is defined by the presence of a fault which strikes N. 35° W. with the downthrown side on the southwest. At an exposure on the Luling-Cibolo road, south of a small cemetery, unconsolidated sands on the downthrown side of the fault are abutting the uplifted sandy shales and beds of calcareous sandstone.

No surface faulting has been found in the northeast end of the field; however, a close study of the areal geology indicates a structural "low" near the W. H. New and Trap Briscoe leases.

Due to the marked absence of fossils in this part of the Wilcox, and due to its lithologic character, it is thought to be of lacustrine or continental origin.

STRUCTURE

A fault or a system of faults trending N. 30° E. is the major structural feature which controls the accumulation of oil in the Salt Flat field. The downthrown side of these faults is on the northwest, and the dip of the fault plane is 55° toward the northwest, as measured in the subsurface by well data and also as computed from surface information. The total or aggregate displacement probably approximates 375 feet. Figures 3 and 4, which are generalized northwest-southeast cross sections, show the position of the beds immediately adjacent to the fault plane where all the displacement actually occurred in one break.

In several places in the Salt Flat field, wells spaced less than 300 feet apart, one of which penetrated the Edwards limestone on the downthrown side of the fault and the other on the upthrown side of the fault, showed approximately 200 feet of displacement, whereas a well farther northwest and on the downthrown side indicated approximately 375 feet of faulting. Figures 5 and 6 show the two possible explanations of this condition. Figure 5 is comparable with a similar condition which occurred in the Luling field.[1] A similar condition has also been found in the Darst Creek field.[2] No downthrown wells have indicated that the condition shown in Figure 5 actually exists in the Salt Flat field; however, it is believed that properly located wells would have indicated this.

Figure 6 shows the beds bending away from the fault plane on the northwest side. As shown from the accompanying subsurface structure map (Plate 4), the Edwards is folded into the fault plane on the upthrown side. These two facts point to the idea that the Salt Flat field is possibly

[1] Ernest W. Brucks, "The Luling Field, Caldwell and Guadalupe Counties, Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 9, No. 3 (May-June, 1925), Fig. 5, p. 639.

[2] Reference is made to the Humble Oil and Refining Company's Dowdy No. A-1, Darst Creek field, Guadalupe County, Texas.

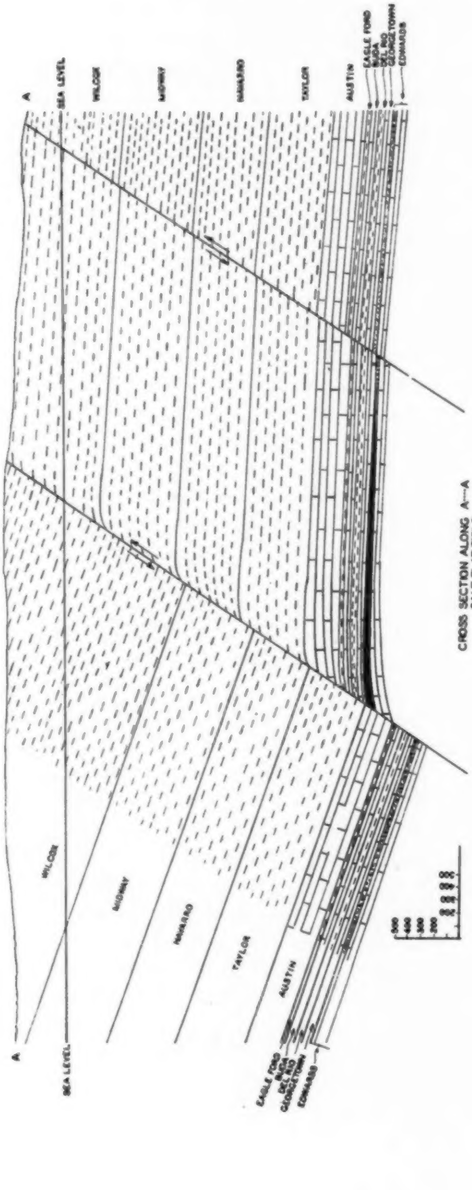


FIG. 3.—Cross section along *A-A* (Plate 4), Salt Flat field, Caldwell County, Texas. Scale in feet.

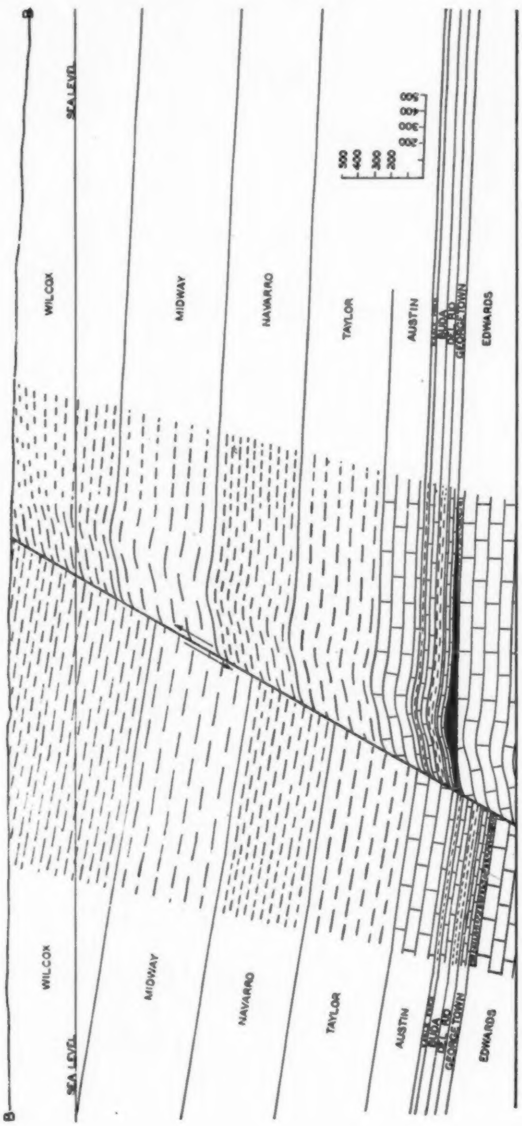


FIG. 4.—Cross section along *B-B* (Plate 4), Salt Flat field, Caldwell County, Texas. Scale in feet.

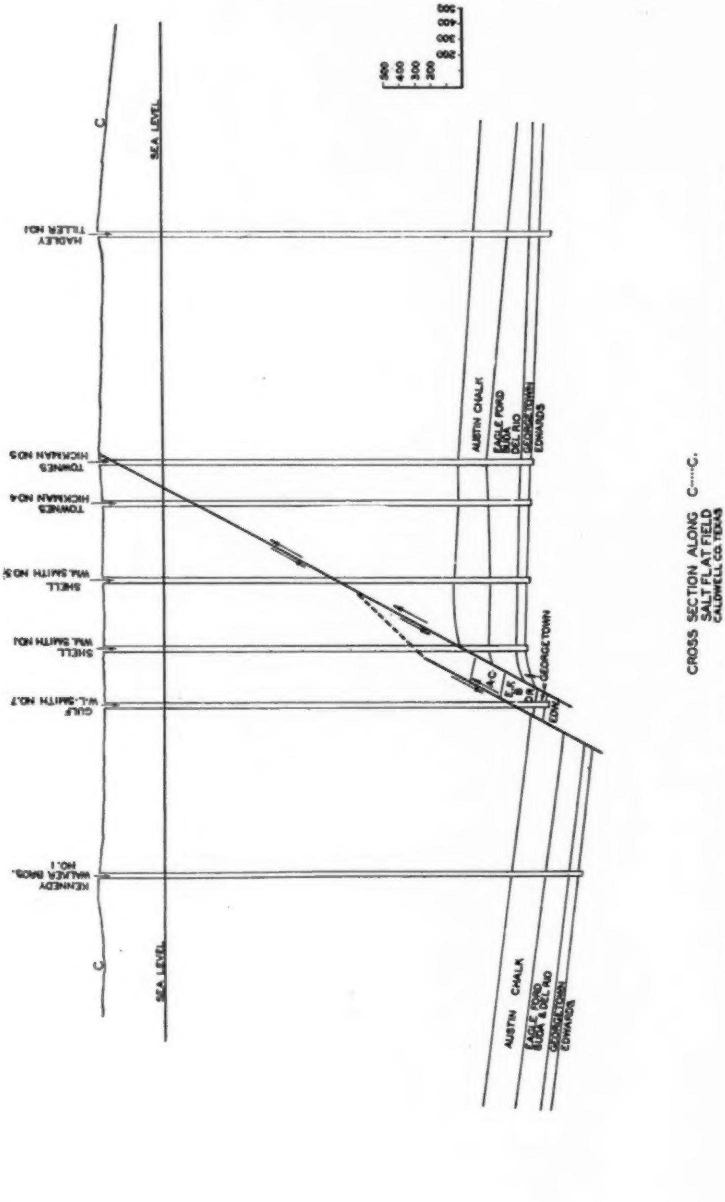


FIG. 5.—Cross section along *C-C* (Plate 4), Salt Flat field, Caldwell County, Texas. Scale in feet.

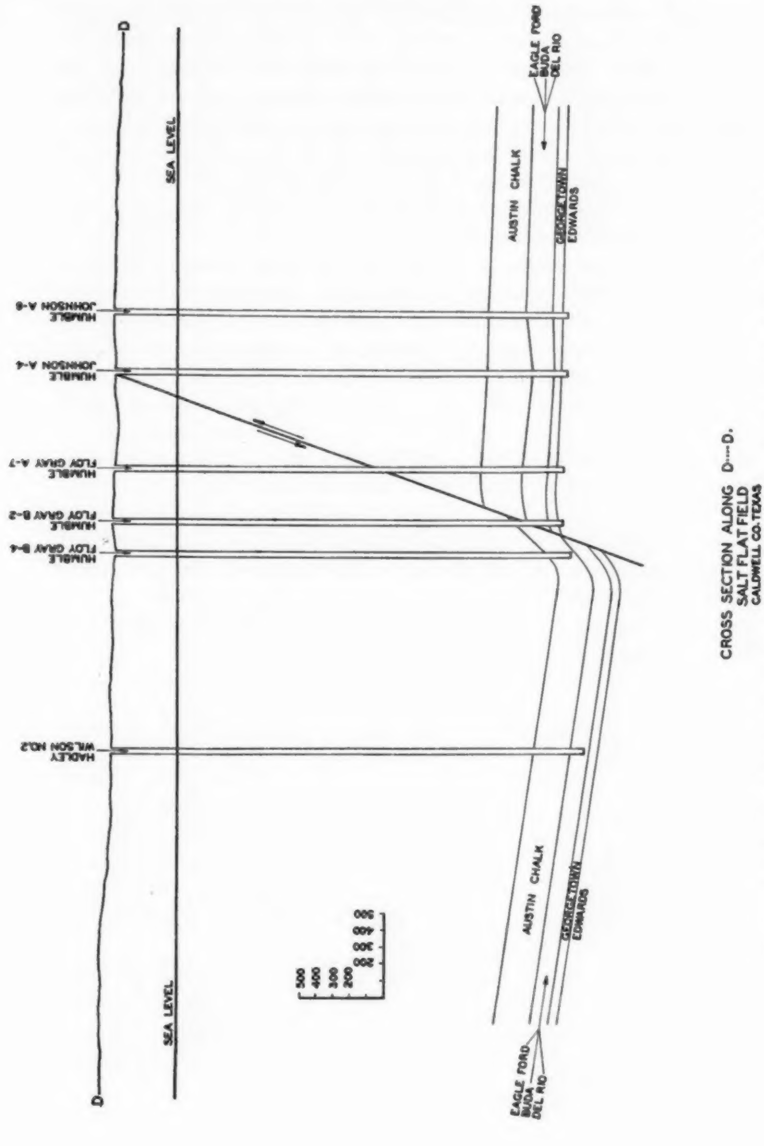


FIG. 6.—Cross section along *D-D* (Plate 4), Salt Flat field, Caldwell County, Texas. Scale in feet.

a faulted anticline. The writers have given particular attention to all the available information on the Salt Flat field in order to clarify this point. They have also studied the published literature on the Luling field,[1] together with the available information on the Darst Creek field, Guadalupe County, and have reached the conclusion that Figure 5 is a more nearly correct interpretation of the structural conditions as they actually exist in the Salt Flat field. The dip into the fault plane on the upthrown side is probably due to drag. The general structure here is that of a faulted monocline.

Several local "highs" trending northeast-southwest occur along the major uplift. The highest of these is located on Cranfill and Reynolds' J. L. Northcutt lease. A structural "low" occurs near the north line of the Gerron Hinds Survey. It is interesting to observe that the largest producer in the field, the Humble Oil and Refining Company's Moses and Baggett No. A-1, occurs in this area. Depth to the producing horizon in the field ranges from 2,250 to 2,330 feet below sea-level, and in general the better wells occur higher on the structure. As previously pointed out, however, many good wells occur in the structural "lows."

The present available information indicates that closure in the Salt Flat field is caused by the main fault on the northwest, the cross fault on the southwest, the regional dip on the southeast, and a structural "low" on the northeast. The dip of the beds in the southwest end of the field is very gentle into the cross fault occurring in the road south of the small cemetery.

OIL, GAS, AND WATER

Various theories have been advanced in explanation of the origin of the Salt Flat oil. It has been argued that the oil had its origin in the beds older than the Edwards limestone, and has migrated up the fault plane and lodged in its present position. In support of this theory it has been cited that similar oil to that produced from the Edwards limestone is encountered and produced from the basal Taylor marl, the Austin chalk, and the Buda limestone in various Salt Flat wells. Also the occurrence of the salt marsh possibly indicates seepage of mineralized water up the fault plane from the lower beds.

It has also been stated by previous authors that the source of the oil is within the Edwards limestone itself. In support of this theory it has been pointed out that deep drilling in the Luling field has disproved the theory that its origin was deep-seated. Evidence of bituminous

[1] Ernest W. Brucks, *op. cit.*

deposits in surface exposures of the Edwards limestone has also been offered by other authors as proof of this theory.

Some evidence also has been offered to prove that the Salt Flat oil had its origin in the marl and shale of the Taylor and has migrated to its present position. The structural disturbance during the forming of the Salt Flat structure and the movement along the fault plane, together with the attendant increased temperatures, have been offered as a process of distilling the oil from the marls and shales of the Taylor. The writers give most credit to the theory that the oil is indigenous to the Edwards limestone; however, they recognize that there is considerable evidence in favor of the theory that the oil had its origin in the marls and shales of the Taylor.

The oil produced from the Edwards limestone in the Salt Flat field is 35.8° gravity (A.P.I.) paraffine base oil, of a greenish color, with a strong hydrogen-sulphide odor. The actual sulphur content is only 0.62 per cent.

Table I is a chemical analysis of a composite sample of Salt Flat crude, as determined by the United States Bureau of Mines Experiment Station, Bartlesville, Oklahoma.

Most of the wells in the Salt Flat field made very little gas when first completed. Most of them flowed for a brief period; however, it was soon necessary to place them on the pump. The total volume of gas being produced daily in the field probably does not exceed 5,000,000 cubic feet. There is one absorption type casing-head gasoline plant with a daily capacity of 3,000,000 cubic feet. The gasoline content is approximately 2.5 gallons per 1,000 cubic feet of gas. Two or three small gas wells were developed at shallow depths. The volume of these decreased rapidly.

Producing wells in the Salt Flat field show some water soon after they are completed and the amount of water produced ordinarily increases in proportion to the depth the well is drilled into the "pay," together with its position on the structure. A few wells which are structurally high produce a large quantity of water when drilled only a few feet into the "pay," and a few wells which are low structurally will show no water when drilled below where water should be encountered. These, however, are exceptional.

On February 15, 1930, the daily average production for the entire Salt Flat field was 25,933 barrels from 318 wells, and for every barrel of oil 3 barrels of water were being produced. Although a large amount

TABLE I*

ANALYSIS OF CRUDE OIL FROM EDWARDS LIMESTONE, SALT FLAT FIELD, TEXAS

Sample 29,729

Station No. 1571, Composite
Humble Pipe Line Company
Sample taken September 25, 1929

Caldwell County, Texas

Specific gravity, 0.846
Per cent sulphur, 0.62
Saybolt Universal viscosity at 100° F., 46 sec.

A. P. I. gravity, 35.8°
Pour point, 45° F.
Color, green

DISTILLATION, BUREAU OF MINES, HEMPEL METHOD

Air distillation 300 cc. Barometer 745 mm. First drop: 37° C. (99° F.)

Temperature °C.	*Per Cent Cut*	*Sum Per Cent*	*Specific Gravity of Cut*	*Degrees A.P.I. of Cut*	*Viscosity at 100° F.*	*Cloud Test*	*Temperature °F.*
Up to 50	0.3	0.3					Up to 122
50– 75	1.2	1.5	0.696	71.8			122–167
75–100	2.6	4.1					167–212
100–125	4.5	8.6	0.725	63.7			212–257
125–150	5.9	14.5	0.748	57.7			257–302
150–175	5.9	20.4	0.766	53.2			302–347
175–200	5.5	25.9	0.785	48.8			347–392
200–225	5.4	31.3	0.801	45.2			392–437
225–250	6.5	37.8	0.816	41.9			437–482
250–275	7.7	45.5	0.829	39.2			482–527
Vacuum distillation at 40 mm.							
Up to 200	4.0	4.0	0.848	35.4	40	20	Up to 392
200–225	7.5	11.5	0.853	34.4	45	35	392–437
225–250	6.4	17.9	0.863	32.5	57	55	437–482
250–275	5.5	23.4	0.875	30.2	80	70	482–527
275–300	6.6	30.0	0.885	28.4	200	90	527–572

Residuum 24.2 per cent. Distillation loss 0.3 per cent.
Carbon residue of residuum 6.0 per cent. Carbon residue of crude 1.5 per cent.

APPROXIMATE SUMMARY

	Per Cent	*Specific Gravity*	*Degrees A. P. I.*	*Viscosity*
Light gasoline (end point 212° F.)	4.1	0.696	71.8	..
Total gasoline and naphtha	25.9	0.748	57.7	..
Kerosene distillate	11.9	0.809	43.4	..
Gas oil	18.5	0.842	36.6	..
Non-viscous lubricating distillate	11.1	0.857–0.877	33.6–29.9	50–100
Medium lubricating distillate	6.1	0.877–0.887	29.9–28.0	100–200
Viscous lubricating distillate	2.0	0.887–0.890	28.0–27.5	Above 200
Residuum	24.2	0.944	18.4	
Distillation loss	0.3	..	..	..

*Analysis by Petroleum Experiment Station, U. S. Bur. Mines, Bartlesville, Oklahoma, made in conjunction with a study of the development and production history of the Salt Flat and other fault fields of east Texas.

of water is being produced, no wells have been abandoned as a result of water encroachment.

No wells have been drilled to test the possibilities of deeper production in the Salt Flat field. There should be approximately 2,500-3,000 feet of limestone, sand, and shale beneath the producing horizon which offer excellent possibilities of deeper production. Deep tests in the Luling field, however, yielded very little encouraging information below the producing horizon, and encountered schist beneath the Comanche.

The presence of salt and sulphur in the Salt Flat water causes considerable trouble in disposing of it. The producing companies have organized the Salt Flat Water Company and are erecting an earthen

TABLE II

The following is a chemical analysis of water from the Humble Oil and Refining Company's J. B. Tiller lease, Salt Flat field, made by the Humble Oil and Refining Company laboratory.

			Per Cent
Sodium	10,420	452.55	38.80
Calcium	1,830	91.30	7.63
Magnesium	667	54.80	4.57
Chlorine	20,800	586.56	48.99
Sulphate	33	.69	.06
Bicarbonate	695	11.40	.95
Carbonate	......	......	......
Hydrogen sulphide	361	......	......
	34,806 p.p.m.	1,197.30	100.00

Silica, Aluminum, Iron	320.00
Primary salinity	75.60
Secondary salinity	22.50
Primary alkalinity	......
Secondary alkalinity	1.90
Chlorine salinity	100.00
Sulphate salinity	70.00
Chlorine-bicarbonate	51.50
Bicarbonate-sulphate	18.50
Calcium-magnesium	1.66
Sodium-(calcium and magnesium)	3.10
Combinations	
Hydrogen sulphite	361 p.p.m.
Calcium bicarbonate	924 p.p.m.
Calcium sulphate	47 p.p.m.
Calcium chloride	4,397 p.p.m.
Magnesium chloride	2,611 p.p.m.
Sodium chloride	26,466 p.p.m.

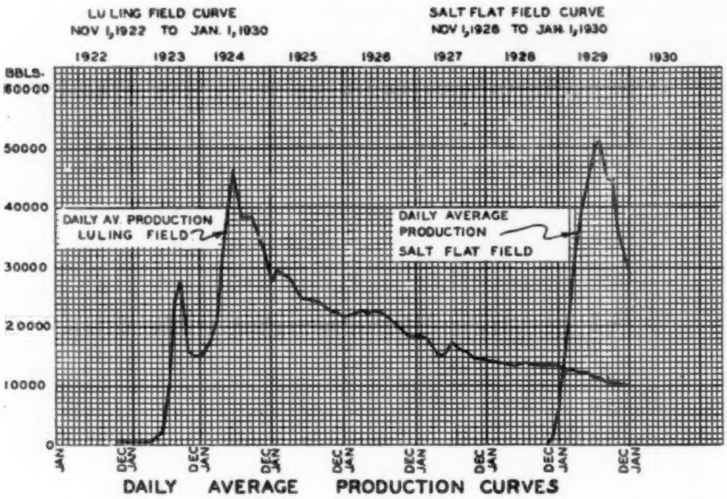


FIG. 7.—Comparative daily average production curves for Salt Flat and Luling fields, Caldwell County, Texas.

storage and evaporation tank southeast of Luling, for the purpose of disposing of the Salt Flat water.

At the time of the discovery of the Salt Flat field there was considerable discussion concerning its ultimate possibilities as a producing field, and more particularly in comparison with the Luling field. Due to several circumstances occurring in the Salt Flat field, such as the early appearance of water, the smaller amount of displacement on the Salt Flat fault in comparison with the Luling fault, its lower position structurally, and the smaller amount of pay sand, the consensus of opinion was that the Salt Flat field would not equal the Luling field in production.

Developments have proved that the productive area is less in the Salt Flat field than in the Luling field, but that the ultimate yield per acre will compare very favorably with that of the Luling field. Even though the amount of saturated section in the Salt Flat field has been small, the average production of the field has been 11,530 barrels of oil per acre up to the end of 1929, or during the first year of its life, which equals approximately one-half the yield per acre to date from the Luling field. The undue pessimism which prevailed during the early development of the Salt Flat field has changed to the extent that to-day

the consensus of opinion is that, despite the early appearance of water, and the small amount of penetration of the pay sand, the ultimate yield per acre in the Salt Flat field will exceed that of the Luling field. As an explanation of this condition we must not overlook the fact that our increased knowledge of the problems surrounding the production of Edwards limestone oil, together with the improved drilling and production methods, has contributed largely to the favorable yield from the Salt Flat field.

TABLE III

(The following tables show comparative production figures in barrels for Salt Flat field for the period ending December 31, 1929.)

PRODUCTION STATISTICS, SALT FLAT FIELD, CALDWELL COUNTY, AS OF JANUARY 1, 1930

Company	*Number of Wells*	*Average I. P.*	*Total Production*	*Average per Well*	*Production (Acres)*	*Average per Acre*	*Acres per Well*
Abercrombie	5	488	242,865	48,573	17	14,280	3.4
Cranfill & Reynolds	8	455	430,003	53,750	15	28,666	2.2
Gulf	58	423	3,196,591	55,113	174	18,371	3.0
Humble	155	381	6,037,047	38,948	599	10,078	3.8
Sun	5	234	220,196	44,039	15	14,679	3.0
Shell	34	662	2,711,989	79,764	121	22,413	3.5
Towns, M. K.	5	108	132,487	26,496	10	13,248	2.0
Grand totals and averages*	270	424	12,971,178	48,041	941	13,784	3.5

*Minor companies are not included in totals.

TABLE IV

BEST LEASES IN SALT FLAT FIELD

Company	*Number of Wells*	*Average I. P.*	*Total Production*	*Average per Well*	*Production (Acres)*	*Average per Acre*	*Acres per Well*
Cranfill & Reynolds							
S. Smith	3	563	283,890	94,630	5	56,778	1.6
Gulf							
Connaly	7	587	609,245	87,027	16	38,077	2.3
Humble							
Moses & Baggett "B"	14	456	878,652	62,761	50	17,373	3.5
J. R. Tiller "A"	4	590	376,365	94,091	15	25,091	3.7
Shell							
F. Tiller	7	1,476	974,356	139,194	20	48,718	2.8
Wm. Smith	5	649	645,768	129,153	10	64,576	2.0
Average lease*		424	....	48,041	....	13,784	3.5

*This average is taken from grand totals and averages for entire field, noted in Table III.

During the early development of the field the oil either was run by the Magnolia Pipe Line Company or was shipped by tank cars. As soon as the field developed sufficient production to warrant additional outlets, both the Humble Pipe Line Company and the Shell Pipe Line Company made pipe-line connections with the field. To-day the Salt Flat field has an outlet of approximately 75,000 barrels per day.

The price obtained for Salt Flat crude has ranged from $0.80 to $1.25 per barrel. It is necessary to treat a large part of the oil before delivering it to the pipe-line companies, most of the treating being accomplished by the use of commercial treating compounds.

TABLE V

SALT FLAT PIPE-LINE OUTLETS

Company	*Size (Inches)*	*Capacity (Barrels)*	*Terminal*
Cranfill & Reynolds	4	7,000	Luling loading rack
Gulf Production Co.	2–4	19,000	Luling loading rack
Humble Pipe Line Co.	8	22,000	Webster
Magnolia Petroleum Co.	4	8,000	Luling tank farm
Shell Petroleum Corp.	6	19,500	Houston via main line
Total		75,500	

DRILLING AND PRODUCING METHODS

Rotary methods of drilling were used exclusively throughout the development of the Salt Flat field. Due to the comparatively shallow depth of 2,700 feet, at which the pay was encountered in this field, the extremely large and heavy-type rotary rigs were not used. The most common type of rotary rig used consisted of two 66-H. P. boilers, Oil Well "Junior" draw works, 21-inch rotary 12×12-inch Ajax Twin cylinder steam drilling engines, 12×16¾×14-inch Lucey or Garner Duplex slush pumps, and 94-foot Emsco steel derricks. A string of 4-inch A. P. I. drill pipe with 2 joints of 6-inch pipe on the bottom was used by practically all operators.

The common practice was to start a 13⅜-inch hole and set and cement 2 joints of 10-inch casing with 20 sacks of cement. A 9⅞-inch hole was ordinarily made into the Georgetown, where 6⅝-inch casing was set and cemented with 100 sacks of cement. It was not necessary to set liner after drilling into the Edwards limestone. Some operators set and cemented both a string of 8¼-inch casing on top of the Austin chalk and a string of 6⅝-inch casing in the Georgetown. This was done

in order to produce from both the Austin chalk and the Edwards limestone; however, this practice was not followed in general. Water for field purposes was secured from the City of Luling, West Fork, and Plum Creek.

Practically all wells in the Salt Flat field are being pumped with individual electric pumping units, such as the Lufkin, the Allis-Chalmers, and the Nutall units. There are probably not more than a dozen wells being pumped with gas engines. The most widely used pumping unit is the Lufkin 5½-inch intermediate unit. The present lifting cost does not exceed 20 cents per barrel. Electric power is being furnished by the Central Power and Light Company.

FUTURE DEVELOPMENTS

The Salt Flat field has not been definitely outlined or closed on the northeast end. Available information indicates, however, that there will be very few additional productive locations northeast of the present proved area.

GEOLOGIC SECTION OF RIO GRANDE EMBAYMENT, TEXAS, AND IMPLIED HISTORY[1]

F. M. GETZENDANER[2]
Uvalde, Texas

ABSTRACT

The geologic section of the Rio Grande embayment of Texas and Mexico has several features peculiar to that locality that have not been adequately studied and presented in the literature. This paper is offered as a contribution to the geologic literature of that region. Areal conditions are described and subsurface information from numerous wells is presented. The term "Rio Grande embayment" is used partly in a geographic sense, as the paper begins with a discussion of the Glen Rose formation, which antedates the genesis of the embayment.

The Upper Cretaceous geology of the region is peculiar in the exceptional thicknesses of the formations; the probable extension and interlapping of faunal ranges; and the occurrence of two or more non-marine series of Navarro age, only one of which appears at the surface.

The Tertiary formations are described and the Bigford as mapped by Trowbridge is shown to extend much farther than the territory covered by his report and map, continuing north into Zavala County, thence east into Frio County, where the formation lenses out and the Carrizo sands and Mount Selman become contiguous.

ACKNOWLEDGMENT

Appreciative acknowledgment is made to the Ryan Consolidated Petroleum Corporation, the Rycade Oil Corporation, and The Pure Oil Company for generous supplies of samples from wells drilled by them; to Knox Tyson and H. C. Vanderpool for valuable information from their notes; to Miss Julia Gardner for assistance on a paleontological problem; and to the Humble Oil and Refining Company, by whose permission this paper is presented and to whose paleontological laboratory the writer is indebted for a large part of the subsurface data upon which it is based.

GLEN ROSE FORMATION AND COMANCHE PEAK LIMESTONE

The oldest bed in the section of which the writer has important first-hand knowledge is the Glen Rose formation. At Eagle Pass and in southwestern Uvalde County this is predominantly limestone with some shale, anhydrite and here and there some sand. At Uvalde it is about

[1]Read before the San Antonio Section of the Association at the Uvalde meeting March 1, 1930. Manuscript received by the editor, July 12, 1930.

[2]Humble Oil and Refining Company.

2,000 feet thick and at Eagle Pass more than 3,000 feet thick. The formation thins northward, being less than 1,000 feet thick at the north line of Uvalde County and about 500 at Rocksprings; 900 at Del Rio, and about 500 at Juno, in northern Val Verde County. As might be expected, the limestones tend to grade into shales toward the north, where shallower-water conditions prevailed.

The Walnut clays are not represented in this region, although they have been reported in Medina County. There are some shales below the Comanche Peak limestone at places on the outcrop, but they contain Glen Rose fossils. *Exogyra texana*, common in the Walnut clays, first occurs in the base of the Comanche Peak limestone. Nothing comparable with the Walnut clays has been reported in the deep wells in Uvalde, Maverick, and Val Verde counties. On its outcrop in Uvalde, Edwards and Real counties, the Comanche Peak limestone has an average thickness of about 60 feet and, ordinarily, is a single bed. So far as the writer is informed, this limestone has not been identified in well drill samples in this larger locality. At Uvalde and Eagle Pass, the cuttings have not disclosed clearly either the base of the Edwards limestone or the top of the Glen Rose. Both these formations, as well as any intermediate beds, are limestones, and the first Glen Rose or pre-Edwards on which local paleontologists and other specialists will risk a decision is the highest *Orbitulina texana* horizon, which, at the outcrop in the longitude of Uvalde, is more than 200 feet, probably 300 feet, below the top of the formation. However, the larger Glen Rose fossils are plentiful, up to the base of the Comanche Peak limestone. Local lithological characteristics of the Glen Rose are veins of gypsum, large cavities filled by pure sulphur, and smaller cavities filled by celestite. Many of the well waters in this formation are mineralized by calcium sulphate, magnesium sulphate, and sodium chloride. At several places along the outcrop in Uvalde County the Glen Rose limestones preserve the tracks of large dinosaurs, evidence that some of the limestones were laid down in very shallow water.

EDWARDS LIMESTONE AND GEORGETOWN LIMESTONE

The Edwards limestone in Uvalde County is about 500 feet thick. At Eagle Pass, possibly including the Comanche Peak limestone, it exceeds 800 feet in thickness. Near Eagle Pass the Rycade Oil Corporation's Chittim No. 2 disclosed 20 feet of coarsely crystalline rock salt at the top of the Edwards or base of the Georgetown limestone. Some of the paleontologists say the age of the salt is Georgetown, although

H. C. Vanderpool of the Rycade believes, on paleontological evidence, that it is Edwards in age. There is 779 feet of limestone above the salt and below the base of the Del Rio clay, a very exceptional thickness of Georgetown limestone.

Böse,[1] who studied the larger fossils of this region, says the Georgetown here should be divided into two members, the lower Georgetown being upper Albian and more closely related to the Edwards, which he considers lower Albian; and the upper Georgetown, with the Del Rio clay and Buda limestone, which is Cenomonian in age.

At The Pure Oil Company's locations in southwestern Uvalde County some of the Edwards limestone is bituminous, and the same is true at some outcrops of the limestone in northern Coahuila, Mexico. In northern Kinney County and southwestern Edwards County there is a flaggy horizon about 200 feet above the base that is bituminous at some of the outcrops. Silicified wood occurs in the basal Edwards in northern Uvalde County, southern Edwards County, and southern Real County. Among many smaller specimens, the writer knows of a fragment of dicotyledon log 18 inches in diameter, near Mine Creek in northern Uvalde County, and a palm-like log 20 inches or more in diameter in southeastern Edwards County, near Barksdale. Notwithstanding these tree remains, the limestone containing them is almost pure and heavily bedded and seems to be a deep-water limestone. It is interesting to speculate about the land on which these trees grew. Was there an island or peninsula near here in the Edwards sea, or did they drift out a long distance at sea from Comanche forests in the Llano-Burnet area?

DEL RIO CLAYS AND BUDA LIMESTONE

We have learned to regard the Del Rio formation as predominantly clays, but west of Devils River and on Pecos River, at places, the clays are missing. At most places, however, the horizon can be followed by means of the yellow limestones containing *Nodosaria texana*. The same is true at places in northern Coahuila, particularly near Remolino, el Macho, and la Babia. This gives us a picture of deeper-water conditions in Del Rio time, southwest, west, and northwest of Del Rio, with shallower water again in the Trans-Pecos country, where the clays reappear.

The top and bottom of the Buda limestone are similar to that limestone farther east. The middle third is marly and weathers more readily than the other parts, leaving scarps at the bases and tops of the limestone on Buda-capped hills, with a sloping profile between. It is a

[1] *Univ. Texas Bull. 2748* (1927), pp. 16, 17, 25.

matter of interest to the writer that the Del Rio clay and Buda limestone vary similarly in thickness. At Uvalde each is about 75 feet thick. In the Rycade Oil Corporation's wells in Maverick County the average thickness of the Del Rio is 260 feet and of the Buda almost the same. Farther south, at the Ryan Consolidated Petroleum Company's wells on the Indio Ranch, the Del Rio is 190 feet and the Buda 180 feet thick.

EAGLE FORD FORMATION AND AUSTIN CHALK

Unlike the Del Rio and Buda, the Eagle Ford and the Austin chalk seem from the well logs to vary inversely in thickness. As one thickens, the other seems to thin proportionately, and the contact between them, lithologically at least, is poorly defined. This observation is limited to central Maverick County, where the aggregate thickness of the two formations is about 1,600 feet. Twenty miles south, in the Ryan Petroleum Corporation's wells, the combined thicknesses of the two formations is 1,200 feet.

Along the Rio Grande there are poor lines of demarcation at both the base and top of the Austin chalk. The Eagle Ford grades into white marls at the top which resemble the chalk more than they do the Eagle Ford with which our laboratory workers are familiar. The Austin chalk grades into soft marly shales at the top which do not give a characteristic chalk drill sample, and they may not be logged as limestone or chalk by the drillers until several hundred feet of the Austin beds have been penetrated.

Adding to the confusion caused by the marls at the top of the Eagle Ford, much of that formation on the Rio Grande consists of flaggy limestones. Near Del Rio these have been called Val Verde flags. In the Big Bend country they are known as the Boquillas flags.

Early in Eagle Ford time began a noteworthy period of vulcanism. The gradation of the extrusives began by middle Eagle Ford, from which time up to middle Escondido large masses of igneous materials were worn down and re-deposited in the Upper Cretaceous sea, resulting in enormous quantities of sedimentary serpentine in eastern Kinney, southern Uvalde, northern Zavala, and southern Medina counties. The total thickness of the section in which more or less serpentine occurs is 1,400 feet. In fact, in one well, the thickness is approximately 1,400 feet between the points of the highest and deepest serpentine. As a rule, however, the thickness ranges from a few feet, limited to a single formation, to several hundred feet, comprising parts of two formations. In some localities these formations are the Eagle Ford and Austin chalk;

in some, the Austin chalk and Anacacho; in others, the Anacacho and Escondido. No serpentine has been found in wells here older than the Eagle Ford, and none so young that it did not have some normal Escondido above it. Of course, this does not mean that there is no altered igneous material along igneous intrusives cutting rocks older than Eagle Ford. Sedimentary serpentines are referred to.

Ordinarily, where there is any considerable thickness of serpentine, there are, interbedded with it, shales, clays, sands, and limestones normal to the respective formations of which the serpentine is part. The serpentine itself contains foraminifers, bryozoans, and larger fossils, though sparingly, and commonly contains fragments of limestone. Also the interbedded normal beds contain fragments of igneous rocks in all degrees of alteration.

The writer has well logs and drill samples that, he believes, will convince any geologist that, in the territory described, which has a length of about 70 miles, east and west, and an average width of 10 miles, there is more than 20 cubic miles of material that was derived from igneous masses which were in existence in Eagle Ford, Austin, and Taylor times. It is probable that not all of these old igneous islands were completely worn away. Some of them were buried beneath the sediments, to be uncovered again by erosion, and they stand to-day as so-called intrusives in the counties named. That may account for the fact that although there is a little metamorphic Edwards limestone and Buda limestone, no metamorphism in any younger rock has ever been reported; also for the fact that these igneous masses do not, ordinarily, have any relation to structural conditions in the beds surrounding them. This does not exclude the idea of late Cretaceous and possibly Tertiary vulcanism in this region. Unquestionably there was vulcanism late in the Cretaceous. The serpentines themselves are cut by dikes and sills, but such later activity was very mild, compared with what happened in Eagle Ford and Austin times.

ANACACHO FORMATION

A formation that is causing much confusion is the Anacacho (Fig. 1), which is Taylor in age. It is unfortunate that the term "Anacacho" was ever used for anything but a strictly local formation in western Uvalde and eastern Kinney counties. There the Anacacho limestone constitutes practically the entire section from the top of the Austin chalk to the lowest Navarro fossils. The only exception is at the west end of the Anacacho Mountains, where there is a little Upson clay, also Taylor in age, between the chalk and the Anacacho limestone. But the

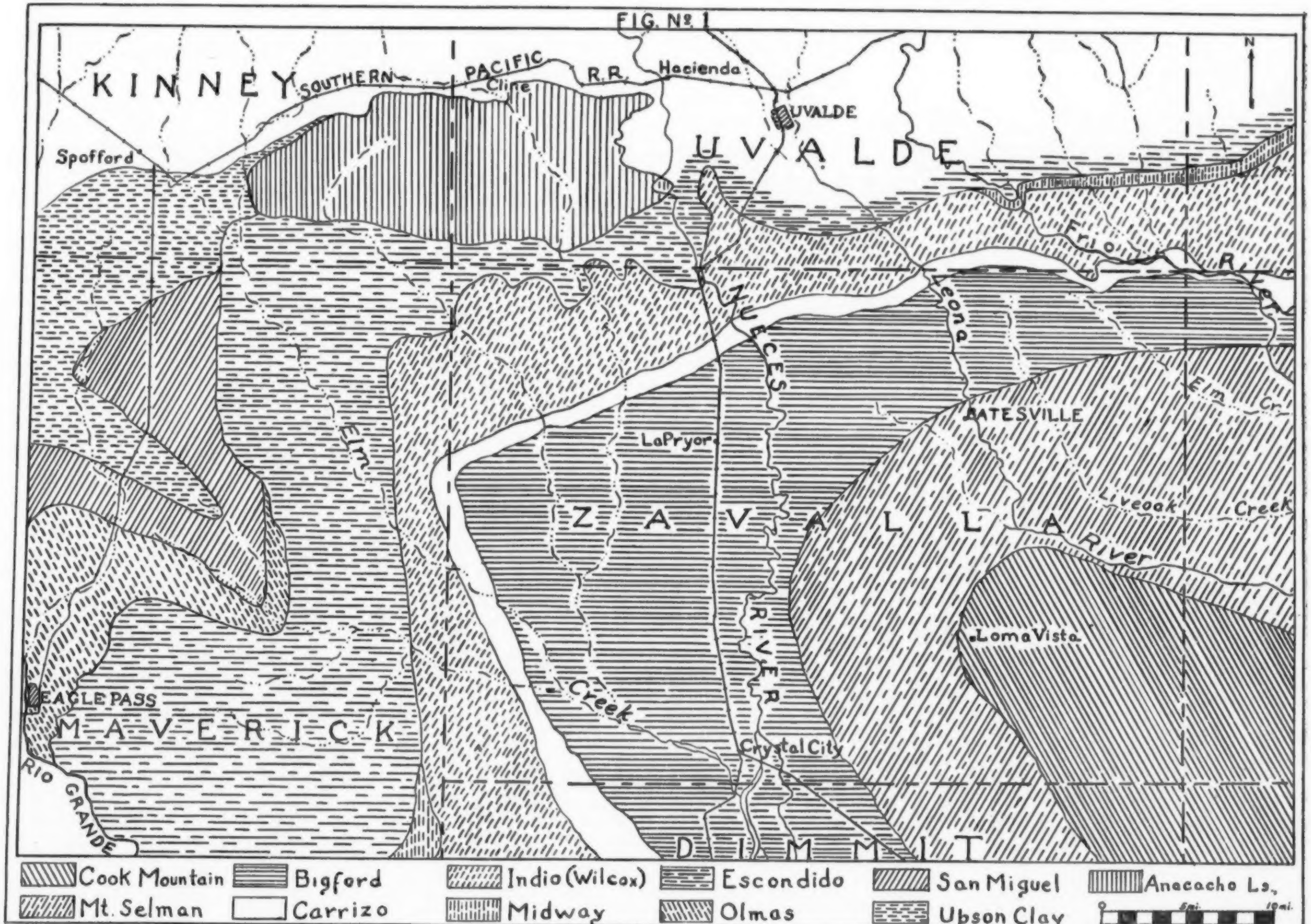


FIG. 1.—Areal geology near Uvalde, Texas.

Upson clay lenses out eastward, and disappears within 2 or 3 miles. The chalk-Anacacho contact is easily followed from that point several miles eastward, in the north scarp of the Anacacho Mountains, and no clay is present there.

Vaughan gave his Anacacho formation the same range in eastern Uvalde County as he did in the Anacacho Mountains, although less than one-half of it is limestone. That is, he includes in it all the beds of Taylor age. In Medina County, Liddle[1] limited his Anacacho to the limestone at the base of the beds of Taylor age, and placed all the younger beds of the Cretaceous in his Escondido. Therefore, in Medina County the Escondido embraces most of the beds of Taylor age, including all the *Exogyra ponderosa*, which Taff[2] made the characteristic fossil of the marls which later were designated as Taylor, although at its type locality on the Rio Grande the Escondido does not include the oldest beds even of the Navarro.

In central Uvalde County the Anacacho, co-extensive with the Taylor fossils, is about 500 feet thick. There is no Anacacho *limestone* west of the Anacacho Mountains, although the thin limestones in the basal San Miguel may be considered as equivalent to a part of it. The limestone ends as abruptly on the west as if the Anacacho sea there had washed against a stationary shore line throughout the entire period.

UPSON CLAYS

Along the Rio Grande most of the beds of Taylor age are represented by the Upson clays. These are simply the Taylor marls become more argillaceous. They are somewhat uniformly about 550 feet thick in several wells spaced throughout a large territory. They contain *Exogyra ponderosa*, and at some horizons, barite concretions, many of which are formed around an *Exogyra ponderosa* as a nucleus. They also contain a costate *Exogyra* which Böse considers *E. costata*, but this form differs considerably from the Navarro or Escondido variety.

SAN MIGUEL BEDS

During late Taylor time on the Rio Grande the land emerged, leaving a strand and near-shore deposit of sands, sandy limestones, and clays. The sands and sandy limestones are very fossiliferous. The clays are similar in superficial characters to the Upson clays, but no fossils

[1] "The Geology and Mineral Resources of Medina County," *Univ. Texas Bull. 1860* (1920), p. 64.

[2] *Third Ann. Rept. Geol. Survey of Texas*, pp. 364 *et seq*.

have been reported in them. The series is about 400 feet thick. The lower part of the San Miguel, according to most of the paleontologists who have studied the fauna, is Taylor in age, although they contain several forms which range up into the Navarro. Some paleontologists who have collected in the formation extensively consider it Navarro in age. It seems probable that along the Rio Grande there is no sharp paleontological break, large faunal groups being considered, anywhere in the Upper Cretaceous. The literature inadvertently suggests this probability. For example, Dumble states that the *Exogyra costata* horizon is at the base of the Escondido. Böse states that *Exogyra costata* characterizes the San Miguel, and at another place he states that this horizon is in the Upper Santonian, which he correlates with the Upson clays.[1]

The writer has collected the costate *Exogyra* in the Upson clays, and at one locality in Maverick County undoubted *Exogyra costata* occurs at the very top of the Escondido, along the foot of a Tertiary escarpment. Other examples might be given.

OLMOS BEDS AND ESCONDIDO FORMATION

Overlying the San Miguel are the coal-bearing Olmos beds, between 400 and 500 feet thick. These are non-marine Navarro. Above these is 750 feet of marine Navarro, the Escondido type section. Böse and Charles Laurence Baker consider the Escondido, in part at least, younger than the Navarro; they would correlate it with the Maestrichtian of Europe, because it contains *Sphenodiscus lenticularis*. Böse would draw a line above the *Exogyra costata* horizon, leaving that fossil in the Navarro, and assign all above it, including the *Sphenodiscus lenticularis* beds, to the Escondido. There seem to be three objections to that suggestion: (1) *Exogyra costata* belongs in the Escondido by the original description of the Escondido section; (2) if a line be drawn above *Exogyra costata*, at one locality at least, it will be in the Tertiary; and (3) in that same locality, if the writer does not mistake the species of *Sphenodiscus*, that ammonite and *Exogyra costata* occur together and no line can be drawn between them. The locality mentioned is on a west fork of Farias Creek in southeastern Maverick County, about ¾ mile west of the Farias ranch house.

In southeastern Maverick County and western Dimmit County, wells drilled by the Humble Oil and Refining Company disclosed 750 feet of Escondido that on lithology and fossil content is correlated with the outcropping Escondido farther north. Below this horizon are marine Navarro beds older than any outcropping Escondido, 420 feet thick in Sul-

[1] *Univ. Texas Bull. 2748* (1927), p. 99.

livan No. 1 and 330 feet thick in the City National Bank No. 1. Below these are 400-600 feet of coal-bearing, non-marine beds, mostly sandy shales containing disseminated lignite, which are correlated with the Olmos formation at Eagle Pass. Below these are 200 feet of marine Navarro sandy shales and impure sandstones. They are very glauconitic, and contain *Inoceramus* prisms and other marine fossils. Next lower are 400 feet of very lignitic beds, but also containing marine fossils of Navarro age. These are muddy sandstones and sandy shales and suggest an estuary deposit. Below these are 325 feet of very micaceous, calcareous sandy shales, with a prolific micro-fauna of the basal Navarro.

The total Navarro in Sullivan No. 1, southeast Maverick County, is 2,830 feet thick. In City National Bank No. 1, western Dimmit County, it is 2,437 feet thick.

TERTIARY SECTION

The Cretaceous-Tertiary contact strikes approximately east and west through southern Uvalde County, but near the west line of the county it bends southwest and crosses the northwest corner of Zavala County and enters Maverick County for 3 or 4 miles. Thence it turns southward to a point 3 miles west of the northwest corner of Dimmit County. Thence, with a curve, it turns southward to the Farias ranch house, thence westward to Biviro Tank on the Indio ranch. In eastern Uvalde County the contact is Escondido against Midway, the Midway being about 1 mile wide at the county line and narrowing to a point, 2 miles west of Frio River. From this last point around the great bend of the strike almost to the northwest corner of Dimmit County, a distance of nearly 50 miles, the contact is Escondido against Indio, except at three or four small outcrops of Midway where streams have removed the Indio. Near the northwest corner of Dimmit County the Midway reappears, rapidly widens, and can be followed continuously into Mexico.

This deep crescent of Indio overlap borders the upper or northwestern end of a large geosyncline which, farther coastward, becomes the Carrizo sand artesian basin, with its axis striking southeastward and passing near Crystal City and Gardendale. It is suggested that this overlapping was caused by the downward warping of the syncline during Indio time, the greater subsidence being along the axis and gradually diminishing with the distance from that axis.

MIDWAY FORMATION

The Midway has no especial peculiarities in this region. It contains an irregularly developed bed of limestone, 25-30 feet thick at some places,

entirely missing at others. The limestone and shales are very glauconitic. The shales in many places contain fossiliferous limestone concretions. In about twenty core-drill holes and deep wells drilled by the Humble Oil and Refining Company in Maverick and Dimmit counties the Midway ranges from 250 to 375 feet in thickness. It has about the same range of thickness in Zavala County.

INDIO FORMATION

In southeastern Maverick County and western Dimmit County the Indio is largely marine. In the core-drill holes and other wells drilled by the Humble Oil and Refining Company, foraminifers and other marine forms were found in the several wells at almost every distance above the base of the formation, so that no general statement can be made that one part of it is marine and another non-marine. The conditions interchanged from point to point throughout the deposition. The large *Ostrea tasex* occurs on the Rio Grande and Loma Dinero Creek about 50 feet above the base. The same oyster occurs 350 feet above the base at a location where the depth to the Midway was determined by the core drill. At other places it occurs still higher in the section. At several places, one of which is near the northeastern corner of the Glass ranch, local sand lenses in the Indio contain small bivalves.

Aside from the marine fauna, the Indio there presents typical phases. It is composed of lignitic, micaceous, sandy shales and calcareous sandstones, limestone concretions, et cetera. In western Dimmit County it is about 800 feet thick.

In Uvalde and Zavala counties no marine fossils have been found in the Indio, except *Ostrea tasex* on Sabinal River, according to the writer's information. South of Uvalde the Indio ranges from 350 to 600 feet in thickness.

CARRIZO SAND

The type section of the Carrizo sand is on Pena Creek, 4 miles west of Carrizo Springs. There it is characteristically a cross-bedded, sand-dune formation, composed mainly of very coarse to fine, rounded grains of quartz, poorly cemented. The formation in that general locality is about 300 feet thick, predominantly sands but with a few shale lenses, some of them 50 feet thick. These shales are similar in all particulars to the shales in the Indio, being micaceous, calcareous, lignitic, and sandy, and containing limestone concretions. Except in these shale partings, and here and there a trace in the cementing material, there is no limestone in the Carrizo and scarcely any mica, at its type locality. Several

localities where the literature reports limestone concretions in the Carrizo are now known to be in the Bigford, a younger formation.

A careful analysis of the laboratory reports on drill cuttings and cores from more than a dozen wells, commencing above and continuing below the Carrizo, shows that descriptions of samples both above and below report common occurrences of limestone (generally from concretions and concretionary beds), mica, biotite, muscovite, et cetera, without the use of one of those terms in describing any sample known to be from the Carrizo. This absence of limestone and the micas, with the extreme porosity and the very general presence of plentiful water (except where above the water head) are fairly good diagnostic characteristics of the Carrizo sand. But inasmuch as sands possessing these features may occur in both the Indio and the Bigford, and as it is probable that some of the sand beds in the Carrizo are not wind deposits, but were laid down under conditions similar to those attending the sands in the older and younger formations and therefore may contain mica, there are no criteria by which the Carrizo may be certainly identified, except in connection with relations to some other bed the identity of which is known.

Deep drill samples of this formation are white sand, composed of colorless to milky quartz grains, with a small percentage of rose or smoky quartz grains. Rarely is there enough cementation to produce rock fragments in the samples. Scattered through the sand grains are small dark to black specks of iron. On weathering, this iron oxidizes, giving the surface Carrizo its red, yellow, or brown color.

This sand is the principal water rock throughout the artesian basin from Crystal City in Zavala County, to Cotulla, Gardendale, and Los Angeles in LaSalle County. A higher sand, probably in the Mount Selman, is supplying some shallow wells near Dilley and Gardendale, but other wells in the same vicinities go farther down to the Carrizo sand for water. The Pulliam or Escondido, formerly considered as the water source in this artesian basin, supplies no large wells and contains no widespread porous sand.

There is a beautifully exposed erosional unconformity at the base of the Carrizo sand at its type locality west of Carrizo Springs.

BIGFORD FORMATION

The Bigford formation consists of gray, gypseous shales and clays with calcareous and ferruginous concretions, many cone-in-cone limestones, and sandstones and sand lenses. It contains much mica, many

plant remains, commonly lignitic, some poorly preserved bivalves, small gastropods, and, less commonly, *Unio*, as near New California in Zavala County, and an undescribed oyster, near Dentonio, in Dimmit County. On micro-examination of well cuttings, its samples present characteristic tan-colored small globular siderite concretions, commonly cemented together in clusters. Some comparisons of these concretions with siderite from the Indio and some other formations show considerable contrast and indicate the possibility of using these concretions for distinguishing the Bigford in well samples. This would be very desirable, as the formation seems to carry no micro-organisms except a very few ostracods and a few *Chara* seed.

Many streams, where crossing the Bigford, divide into two or more branches which re-unite and again separate, presenting a sort of extended delta pattern. Small and large lakes in old abandoned channels are numerous. Structural attitudes of the beds and surface relief may contribute to this feature, but it seems to be general and some characteristics of the beds themselves must have a bearing on the condition, as it is not common in other formations. Similar conditions have been observed in some Yegua localities.

In Zavala and Dimmit counties the Bigford ranges from 600 to 700 feet in thickness. E. W. Berry, who studied the flora of the Bigford, states that it is Wilcox in age and, accordingly, Trowbridge has subdivided the Wilcox, designating the Carrizo sand as the middle member, with the Indio at the base, and the Bigford at the top.

Trowbridge did not differentiate the Bigford farther north than Carrizo Springs, which was near the northern limit of the area covered by his report. The writer of this paper had previously studied and partly mapped a unique bluish-white, very fine-grained, non-calcareous sandstone, younger than the Carrizo sand, and containing imprints of grass-like leaves. He carried this bed in his notes as the "Mills bed," because he first studied it on the O. A. Mills ranch in Zavala County. It occurs in a long line of disconnected outcrops in Frio and Zavala counties. On studying Trowbridge's Bigford in the vicinity of Dentonio, Dimmit County, he found a large outcrop of this sandstone within that formation. Working northward, other outcrops of the same bed were found, connecting the one near Dentonio with the line that had been previously mapped. The writer mentioned this bed to Trowbridge, who probably checked part of the line of the outcrop. Later, Julia Gardner followed the bed through Zavala County into Frio County, and members of the United States Geological Survey have advised the writer, in conversa-

tion, that she confirms his conclusion that the Bigford is represented as far east as Seco Creek in Frio County. More recently the writer has found the Bigford, including this sandstone, north of Big Foot in eastern Frio County, where the formation seems to lens out, and the Carrizo sand and Mount Selman become contiguous formations.

The writer had also mapped a thick section in Zavala County, above the Carrizo sand, and seemingly not Mount Selman or Cook Mountain, which included the sand mentioned. Having demonstrated that this section and the Bigford contain an identical bed, he proved the identity of this section in Zavala County with the Bigford formation itself.

TEST-PIT EXPLORATION IN COASTAL PLAIN OF SUMATRA[1]

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ABSTRACT

In order to examine properly the later Tertiary shales and bedded sandstones of southeastern Sumatra, it is necessary first to penetrate the lateritic mantle. This has been accomplished by digging systematically located pits. The method of work, and the results of observations made of this blanket material, lying beneath the jungle-covered regions of Sumatra, are described and the value of the method is discussed.

INTRODUCTION

The geologic method employed in any territory depends largely upon the accessibility of the data desired as well as upon the preference of the geologist. In securing accurate information regarding the structure and stratigraphy of prospective oil fields in the tropics, different methods are used to overcome certain obstacles not generally present in more temperate regions. One common method is that of following stream courses in search of outcrops. Another is the pit method. Where outcrops are scarce and where streams are too small and too full of snags for boats, and too deep for wading, the pit method has been successfully employed. This method, with modifications, has been used by geologists in Sumatra. The following discussion is based on the writer's experience after examining hundreds of pits in the Residency of Palembang, Sumatra, Dutch East Indies.

The pit method has an advantage over the outcrop method in showing the actual position of the beds. The pits are commonly put down into the unweathered strata, where it is improbable that much surface movement has occurred. The uniformity of pit-spacing insures also a better general distribution of geologic data. It does not, however, result in a continuous unbroken section, nor can it be used effectively for following any one particular bed, unless a great number of pits are dug.

PROCEDURE

In Sumatra, the general procedure is first to cut straight trails through the jungle by the use of natives with *parangs* (long chopping

[1]Manuscript received by the editor, June 16, 1930.

[2]Chief geologist, California State Division of Mines.

knives) and to put up signs where pits are to be dug. The alignment of trails is made by the use of compass and stakes. The experienced native who does this also measures the trail approximately with a long piece of rattan obtained from the jungle and marks the position for each of the pits. This necessitates careful planning and laying out of the work previous to entering the field. The trail makers are followed by pit diggers (commonly Chinese contract workers), who make holes deep enough to pass well into the unweathered formation. As soon as possible the holes are examined by the geologist. Later a native surveyor passes along the trail, not only locating the holes accurately with his instrument, but making a topographic sketch map as he goes. Cross trails are ordinarily constructed at the same time the main trail is being cut. The main trail generally follows the main trend of the structure. The spacing of the cross trails and of the pits along them depends upon the amount of detailed information desired and the complexity of the structure.

The *mantri*, or native surveyor, is trained with *tranche montagne* and theodolite, both rather cumbersome instruments. The plane-table, as used by geologists in America, is hardly known to these natives. It is not a very practical instrument to use in the jungles, where few side-shots can be taken and rain and dampness would soon ruin the paper of the table. If it is desired, the *mantri's* work may be traced in the field from the broad page of his note-book and white prints made in a photographic printing frame taken into the field. In this way topographic progress sheets may be kept up which are useful to the geologist for making sections and drawing structural contours. The structural contours are drawn from dip and strike data. The contour spacing is established by means of a graphic scale which shows the spacing for degree of dip. This graphic method of structural interpretation is also guided by a comparative lithologic study from pit to pit. Fossil beds may be encountered in the pits, and these are generally very useful in correlation. Systematic note-taking is facilitated, for each pit is numbered by a brass plate tacked to a tree.

The top edge of the pit is timbered, but most of the wall is left to stand up by itself. Notches are cut in two opposite sides for the feet and hands of the geologist in climbing in and out. The hole is made a meter square, and at the bottom is a smaller hole to collect dirt and water and to make it easier to bail the muddy contents out of the hole. The depths of the pits range from a few meters to more than 7, the average being 4½ meters. The jungle is cleared off around the hole to let in the light, and even with this provision the examination can hardly be made

earlier than 9 or later than 3 o'clock, so dark are the woods when the sun rays come at low angle.

GEOLOGIC DATA SECURED BY PIT METHOD

The most important data obtained are those of dip and strike. The lithologic character of the rock is noted. Local jointing, fissuring, faulting, warping, and any other features are also studied. The cramped position of the geologist, who generally is most interested in the very bottom of the hole, upon which his feet rest, is not favorable for sighting along the strike of the beds. The strike is best taken by use of a small, simple level placed on the surface of a freshly cleaved bedding plane, broken loose by a very broad chisel-edged hammer. Perhaps a square foot or more is clearly exposed. The compass is placed against the straight edge of the level and the reading clearly taken as the light from the sky falls on the face of the compass. The straight edge is then placed on the dipping surface and the clinometer placed upon it and read. A sample is collected, numbered, and placed in a sack.

WEATHERED MANTLE

The weathered mantle covering is a residual product, in most places, of the formation beneath, but it has undergone complete change. In few places does it show any distinct sign of the structural position of the underlying fresh strata. It is a clay, oxidized and characterized by iron-stained patches or concretions of limonite. It is mottled (red, brown, yellow, and white), although the unweathered formation is dark (olive, blue, or nearly black). The mantle is very pervious to water and contains many little passages. Exactly how these passages have originated is a question. There is not very much evidence of any holes of burrowing animals. Roots of jungle trees, which may account for some of the holes, do not extend far below the surface and are not encountered in the pits below approximately a meter from the surface.

DRAINAGE OF METEORIC WATER

The rapid passage of water through this pervious mantle during and immediately after hard rains is very noticeable and probably accounts for the complete change which the residual material has undergone. Where the underlying formation is a loose sandstone, there is not such a distinct change between it and the weathered formation, but the mantle is generally much thicker. In the dense shales, the freshly broken strata ordinarily appear nearly dry in comparison with the water-soaked surface clays.

The soaking of the mantle with water during a hard rain and the immediate release of it after the rain causes the streams to rise rapidly and to fall equally as fast. Thus the immediate run-off is not confined to the surface of the ground, but to the top of the fresh formation lying several meters beneath the surface.

RESULTS OF STUDY OF MANTLE

Most of the Tertiary sediments of southeastern Sumatra are covered by a mantle of weathered clayey or lateritic material several meters in thickness. Although it is remarkably persistent and evenly distributed throughout the area, it varies a little in thickness and in general appearance according to the lithologic character and the steepness of dip of the underlying strata, and according to the position of the pit with reference to the topography.

In general, shales are not weathered as deeply as sandstones and limy formations, but the completeness with which the shales are altered is noticeable and the demarcation between the light red and yellow unstratified clay and the dark, well-laminated shales beneath is so distinct that even the coolie pit-diggers recognize it with enthusiasm when finally they break into it. Three or four meters depth generally is sufficient to pass through this mantle and another half meter exposes the formation.

The sandstones ordinarily are weathered much deeper. The alteration is not as complete as with the shales, however, and if limy fossil shells are present, a lumpy concretionary material may occur. Ferruginous, calcareous, and a few siliceous concretions are scattered through the clay. The color of the sandy residual clay is commonly red. This fact is due to the weathering of fine-grained pyrite and marcasite which occur throughout the sandstones.

The contact between the weathered and the unweathered material is transitional and not all the bedding planes are distinct. In places the hole may be dug through an unweathered zone and into weathered material again. The average thickness of this sandy clay mantle is 4 or 5 meters, though 7 or 8 meters may be penetrated without encountering the underlying unweathered sandstone.

Limestone generally occurs in the pits as irregular residual boulders, resting in a matrix of reddish clay, the result of subsurface decomposition.

In areas where the dip is steep (more than 25°) the mantle may not be very thick. In places the bedding is visible in the mantle clay of steep-

ly dipping strata, although there are very few signs of it if rocks underlying the surface are flat.

In low marshy areas the mantle may be partly alluvial. Although the alluvium is not very thick, except along river courses, the cover is too wet for pits to be dug in it profitably. The mantle in such places is probably at least 10 or 12 meters thick.

Although one might expect to encounter it, bed-rock does not generally occur at shallow depth on the sides of hills. More commonly, the mantle is found thinner on the higher topographic points, as on the crests of ramifying ridges.

The metamorphic and the intrusive igneous rocks of Sumatra are harder and more resistant than the Tertiary sediments, and occur in the more mountainous sections of the country. They do not generally have a thick mantle of weathered clay, only a meter or two of reddish residual clay. There are many rugged hills with sharp rocky exposures. The softer volcanics, however, are weathered to considerable depths.

The older Tertiary sediments, such as the conglomerates of the Eocene, flank the upraised mountains where the crystalline rocks are exposed. These coarse Eocene sediments resist weathering to a greater extent than do some of the older crystalline rocks.

The lower Miocene strata are, for the most part, fairly consolidated and laminated shales, in places containing limestone beds. Exposures of the Miocene are much less common than those of the older rocks, and the mantle is only 3 or 4 meters deep in many large areas. The upper Miocene is more sandy, outcrops are scarce, and the mantle ranges from 3½ to 7 meters deep. The Pliocene strata are softer, more tuffaceous, and contain lignite beds in the lower part. Alteration is not uniform, and the clays are not as red as in the areas of older formations.

In general, the color of the mantle clays anywhere in the whole area is probably much lighter than that of the source rock. Mottled yellow, red, brown, and gray are common colors. In a few places the clay is a buff-white, although the source rock is a dark olive-gray. Decomposed lignite beds lend a dark brownish color. Nodules of limonite and hematite (forming laterite) are more common in the residual material of calcareous pyritic sandstones. Although red is the very pronounced color in the subsoil of the whole region, it is not everywhere present.

The completeness with which the mantle rock is altered, even to the extinction of any signs of bedding planes, is significant, for this material can not be used in mapping geologic structure. The mantle seems to be

universally of such a porous nature that ground water finds ready drainage through it.

The rough hilly character of the areas covered by the Miocene in the coastal region of Sumatra resembles the hilly wooded sections of the southern part of the United States. Many of the slopes are as steep, but outcrops in the tropical country are much scarcer. When the streams are low, exposures may, in places, be found at low points on the banks, projecting from underneath the mantle.

CONCLUSIONS REGARDING PIT METHOD

The conditions which make the pit method advantageous are: (1) region where outcrops are scarce or practically inaccessible; (2) region where cheap labor may be secured; (3) mantle covering whose average thickness is considerably less than 7 meters; (4) underlying formation, preferably of shale, in which the dip and strike can be measured with certainty; (5) no large amount of hard stony material to dig through; and (6) favorable weather conditions.

Under these favorable conditions, the pit method is found to give satisfactory results of the following nature: (1) reliable dip and strike measurements; (2) uniform data which do not depend merely on scattered outcrops; (3) information wherever the geologist wishes to obtain it; and (4) complete and uniform set of unweathered specimens.

"LOWER PLIOCENE" IN EASTERN END OF PUENTE HILLS, SAN BERNARDINO COUNTY, CALIFORNIA[1]

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ABSTRACT

A previous author, although expressing the opinion that certain strata in the Puente Hills might be of Fernando (Pliocene) age, has mapped them as Puente (upper Miocene) because of the fact that they seemed to lie conformably upon the Puente and to carry no diagnostic fossils or other conclusive evidence of Pliocene age. This paper records a "Lower Pliocene" micro-fauna from these strata in support of the previous author's expressed opinion, and correlates them with certain horizons in the Los Angeles and Ventura basins. It also shows a possible correlation with the lower part of the Wildcat series of Humboldt County.

The raising of a question regarding the existence of Pliocene beds in the eastern part of the Puente Hills recently called to mind a small patch of "Lower Pliocene" material which was noticed during the course of a field trip into that area in the spring of 1927, and suggested the idea that it might be of sufficient significance to be worthy of record.

The area examined lies in the extreme southern part of San Bernardino County and extends a short distance into Riverside and Orange counties, as shown on the accompanying map (Fig. 1) based upon an enlargement of a part of the Corona Quadrangle of the United States Geological Survey's topographic maps.

It is a part of the Puente Hills fault block, bounded on the northeast by the Chino fault and on the southwest by the Whittier fault, with perhaps a buried fault[3] between. Two synclines and a small eastward-plunging anticline extend southward and eastward from the western part of this area, the anticline and the northern syncline merging toward the east through a small structural terrace into the northern flank of the southern syncline. The southern syncline plunges toward the east throughout its western half, but the work of the writers does not indicate a continuation of this plunge beyond the point where the anticline and

[1]Manuscript received by the editor, August 13, 1930.

[2]Collaboration by permission of F. C. Ripley, manager, Chanslor-Canfield Midway Oil Company, Los Angeles, California.

[3]Walter A. English, "Geology and Oil Resources of the Puente Hills Region, Southern California," *U. S. Geol. Survey Bull. 768* (1926), p. 58.

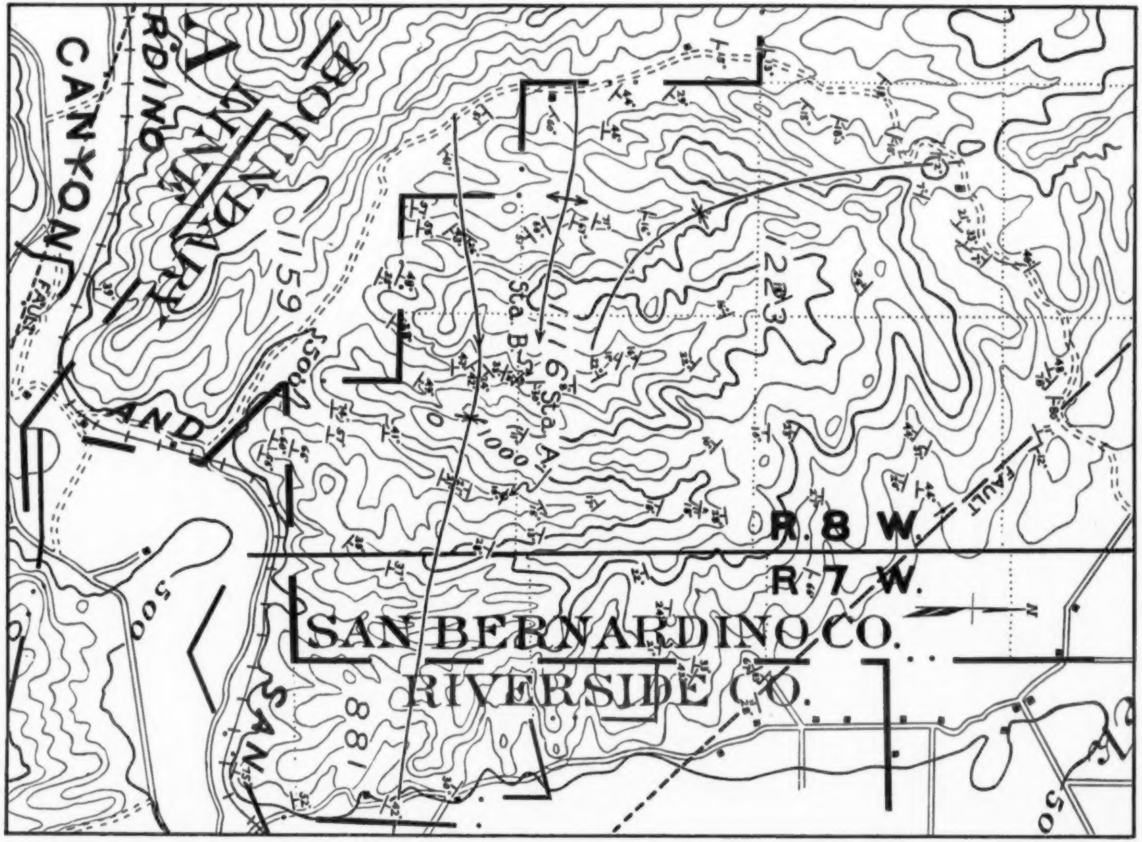

FIG. 1.—Map showing location of "Lower Pliocene" samples with respect to topography and geologic structure. Eastern end of Puente Hills, San Bernardino County, California. Contour interval, 100 feet. Scale: 1 inch = 3,700 feet.

the other syncline disappear. Such a continuation is, however, suggested by the areal mapping of English.[1]

The samples in which "Lower Pliocene" *Foraminifera* were found were taken at the stations indicated on the map as "*Sta. A*" and "*Sta. B.*"

At station *A* zones of blue, gray, yellow, and brown shale 30-40 feet thick are separated by 6-foot zones of medium fine- to coarse-grained sandstone and coarse conglomerate. The thickness of the bedding within the shale zones ranges from thin lamination to about 1 foot; that within the sandstone and conglomerate zones from about 6 inches to 1 foot. The blue shale weathers to blue-gray and makes up the thicker beds, the yellow and brown material being for the most part thin-bedded or laminated. The *Foraminifera* are from a sample of the blue shale.

At station *B* sandy shale occurs with fine-grained sand, both being blue upon fresh exposure. The *Foraminifera* are from the sandy shale.

The following lists of species indicate clearly that the material from stations *A* and *B* is of "Lower Pliocene" age. The writers are indebted to Joseph A. Cushman for the identification of *Spiroloculina depressa* d'Orbigny, *Sigmoilina tenuis* (Czjzek), *Robulus americanus* (Cushman), *R. nikobarensis* Schwager, *Nodosaria parexilis* Cushman and K. C. Stewart, *Nodogenerina* (?) sp., *Frondicularia advena* Cushman, n. var., *Bolivina subadvena* Cushman, n. var., *Cassidulina* cf. *pulchella* d'Orbigny, *C.* cf. *subglobosa* H. B. Brady, var. *quadrata* Cushman and Hughes, and *Globigerina conglomerata* Schwager, and for the checking of identifications of the remainder of the species listed. *Frondicularia advena* Cushman, n. var., and *Bolivina subadvena* Cushman, n. var., will be named, described, and figured in a subsequent paper now in preparation.

There seems to be only a small patch of this "Lower Pliocene" material lying in the trough of the syncline. Underlying it, and cropping out both on the north and on the south are conglomerates, sandstones, and chocolate-colored shales which seem to be of Miocene age. Samples of this latter material were sent to G. Dallas Hanna of the California Academy of Sciences in 1927 to be examined for diatoms, and he has kindly submitted the following statement for use in this paper.

> The lower shales unquestionably resemble material which has usually been referred to the Miocene of that region, although it was not possible to find any determinable diatoms or other fossils to prove this age. In La Habre Canyon near the top of the grade some well-preserved diatoms have been collected from shales not differing greatly physically from your samples, and these

[1] *Op. cit.*, Pl. 1.

STATION *A*

Robulus nikobarensis Schwager	R
Nodosaria parexilis Cushman and K. C. Stewart	R
Frondicularia advena Cushman, n. var.	C
Nodogenerina (?) sp.	VR
Lagena sp.	VR
Buliminella curta Cushman	C
Bulimina inflata Seguenza	VR
Virgulina nodosa R. E. and K. C. Stewart	VR
Bolivina seminuda Cushman, var. *foraminata* R. E. and K. C. Stewart	R
B. sinuata Galloway and Wissler	A
B. subadvena Cushman, n. var.	C
Uvigerina peregrina Cushman	A
Much more variable than the Atlantic forms	
Valvulineria araucana (d'Orbigny)	R
Gyroidina soldanii d'Orbigny	R
Pulvinulinella pacifica Cushman	VR
Cassidulina cushmani R. E. and K. C. Stewart	R
C. cf. *pulchella* d'Orbigny	R
More keeled than typical *pulchella*	
C. cf. *subglobosa* H. B. Brady, var. *quadrata*, Cushman and Hughes	VR
Planulina ornata (d'Orbigny)	R
Cibicides sp.	C
Echinoid spines	R

STATION *B*

Textularia flintii Cushman (?)	R
Clavulina communis d'Orbigny, cf. var. *pallida* Cushman	R
The writers' specimens, although close to this variety, have a much rougher surface than the typical form	
Spiroloculina depressa d'Orbigny	R
Sigmoilina tenuis (Czjzek)	VR
Pyrgo murrhyna (Schwager)	VR
Only two poorly preserved specimens were found	
Robulus americanus (Cushman)	A
R. americanus (Cushman), var. *spinosus* Cushman	C
Nodosaria sp.	R
N. sp.	VR
Glandulina laevigata d'Orbigny	VR
Frondicularia advena Cushman, n. var.	R
Plectofrondicularia californica Cushman and R. E. Stewart	R
Buliminella curta Cushman	R
Bolivina sinuata Galloway and Wissler	A
B. subadvena Cushman, n. var.	C
Uvigerina peregrina Cushman	R
Valvulineria araucana (d'Orbigny)	VR
Eponides tenera (H. B. Brady)	R
Cassidulina cushmani R. E. and K. C. Stewart	R
C. cf. *pulchella* d'Orbigny	R
More keeled than typical *pulchella*	
C. cf. *subglobosa* H. B. Brady, var. *quadrata* Cushman and Hughes	VR
Globigerina conglomerata Schwager	R
Orbulina universa d'Orbigny	VR
Planulina ornata (d'Orbigny)	R
Cibicides sp.	R
Echinoid spines	R

do contain well-preserved diatoms, which permit a positive identification of the formation as Miocene. Even at this point, however, the material does not appear to be the equivalent of extreme uppermost Miocene — that is comparable to the uppermost Monterey at Monterey, California. A detailed study of the La Habre Canyon diatoms has not yet been made, but their equivalent in the standard Monterey section appears to be several hundred feet below the top.

English, in discussing the horizon which he mapped as the upper member of the Puente, made the following statements regarding the member as a whole.[1]

> The conglomerates are very similar in character to those in the Fernando, and it is possible that some of them are actually of Fernando age.....but in the absence of any indication of unconformity it is thought preferable to include the whole succession in the Puente.
>
> . . . .
>
> No diagnostic fossils have been found in the beds mapped as the Puente formation.....The age determination therefore rests on the position of the formation between the middle Miocene Topanga and the Pliocene Fernando and on such correlations as may be made on the basis of lithologic character. ....It is of course useless to expect any exact correlation with the formations in other areas, as individual beds of considerable thickness can not even be correlated between separate outcrops within the small area of the present investigation.

In referring to the particular area of the upper member "which is mapped along the axis of the syncline at the east end of the Puente Hills," the area from which the writers' samples come, English adds:[2]

> It is possible that this sandstone belongs to the Fernando, as it differs in lithology from the typical Puente yellow sandstones and as it resembles the lower part of the Fernando in the Santa Ana Canyon oil field.

The finding in this area of a fauna which may with certainty be placed in the "Lower Pliocene" not only tends to substantiate the idea which English expressed regarding the possible Fernando age of at least a part of the upper member of the Puente, but also suggests the possibility of correlating separate exposures of the upper member which seem to carry Fernando beds in different parts of the Peunte Hills area, and of correlating these exposures with the "Lower Pliocene" of other districts outside of the Puente Hills area. It may also throw some light upon the relationship which exists between the "Lower Pliocene" and the Puente, especially if there proves to be no unconformity between the two in this area.

[1] *Op. cit.*, pp. 36, 37, and 39.

[2] *Op. cit*, p. 38.

The term "Lower Pliocene" is employed here in the same sense as in a recent paper on new species and varieties of *Foraminifera* from the Ventura Quadrangle.[1]

The fauna from stations *A* and *B* may be correlated with the "Lower Pliocene" of the Los Angeles and Ventura basins, and a large percentage of the species occur also in the Wildcat series of Humboldt County, California, two of the most characteristic, *Plectofrondicularia californica* and *Bulimina inflata*, being also characteristic of the lower part of that series.

In the Los Angeles Basin this "Lower Pliocene" is best studied from well sections. In most of the oil fields it is first encountered at depths below 2,000 feet and seems to range from about 2,000 to 3,000 feet in thickness. Two easily accessible surface exposures which afford excellent opportunity for collecting representative *Foraminifera* occur in the Palos Verdes Hills, one in a small ravine at the northern end of the D. M. S. & B. Quarry ("Lomita Quarry"), and the other at Malaga Cove.

In the vicinity of Ventura the face of the Sulphur Mountain overthrust is marked for the most part by "Lower Pliocene" shales which have been faulted up along with Miocene and older formations and dragged under them as a result of overturn and thrusting. To the best of the writers' knowledge, however, these shales have not yet been encountered by any of the wells of the Rincon or Ventura Avenue fields south of this fault, although the Rincon field has been tested to depths below 7,500 feet and the Ventura Avenue field below 8,000 feet. A very convenient exposure for collecting representative "Lower Pliocene" *Foraminifera* near the face of the Sulphur Mountain overthrust is to be found in a road cut at Rincon Point about 150 yards east of the Ventura County line along the coast highway from Ventura to Santa Barbara, and in these shales, as well as in those exposed in the Palos Verdes Hills, occur practically all of the species which are listed from the writers' Puente Hills material, including several good "Lower Pliocene" markers.

[1]Roscoe E. and Katherine C. Stewart, "Post-Miocene Foraminifera from the Ventura Quadrangle, Ventura County, California—Twelve New Species and Varieties from the Pliocene," *Jour. Paleont.*, Vol. 4 (1930), No. 1, pp. 61-62.

DOES PETROLEUM FORM IN SEDIMENTS AT TIME OF DEPOSITION?[1]

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ABSTRACT

Chemical analyses of large quantities of recent marine sediments from the richest areas located during a survey of the distribution of organic matter in various types of modern deposits indicate that liquid petroleum probably does not occur in sediments at the time of their deposition, and that if it is present, it is in very small amounts, certainly less than 3 parts per 100,000. Therefore, petroleum present in newly deposited sediments is not an important factor in the genesis of oil. Presence of small quantities of solid paraffines suggests that some constituents of petroleum occur in fresh sediments. Fatty and oily substances constitute less than 1 per cent of the organic content of the marine sediments. Presumably much, if not most, of the petroleum comes from the remaining 99 per cent of the organic matter. Fatty acids ranging from cerotic ($C_{26}H_{52}O_2$) to melissic ($C_{30}H_{60}O_2$), comprise practically all the fatty acids observed and they constitute from 0.002 to 0.006 per cent of the sediment. Organic sulphur compounds form about 0.03 per cent of the deposits. Free sulphur is a common minor component of all the sediments, and ranges from 0.02 to 0.1 per cent in quantity.

INTRODUCTION

The question of whether or not petroleum forms in sediments at the time of their deposition is of great interest. In the writers' investigations on "The Origin and Environment of Source Sediments," conducted under the auspices of the American Petroleum Institute, they have recently obtained data which throw light on this problem. A preliminary survey of the distribution of organic matter on the sea bottom demonstrated the presence of a few regions in which deposits rich in organic matter are now forming. Large quantities of sediments from four of these rich areas were extracted with carbon tetrachloride and the extracts were examined in detail. As petroleum is soluble in CCl_4, in analyzing the extracts,

[1]This paper contains preliminary results of an investigation on "The Origin and Environment of Source Sediments," listed as Project 4 of the American Petroleum Institute research program. Financial assistance in this work has been received from a research fund of the American Petroleum Institute donated by John D. Rockefeller. This fund is being administered by the Institute with the coöperation of the Central Petroleum Committee of the National Research Council. Manuscript received by the editor, August 25, 1930.

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the writers gave special attention to ascertaining the distribution of liquid hydrocarbons in these, the richest marine organic deposits which have come to their attention.

No liquid hydrocarbons were detected. The maximum quantity of liquid hydrocarbons that might have been present without being observed is less than 3 parts per 100,000. This indicates that petroleum present in sediments at the time of their accumulation can not be a major factor in the formation of commercial oil pools. However, the presence of small amounts of solid paraffines suggests that some normal constituents of petroleum occur in newly deposited sediments.

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This paper represents the joint work of the two writers, but the chemical analyses were made by Wu.

ANALYSES OF SEDIMENTS

GENERAL REMARKS

Description of sediments.—Each of the four sediments selected for analysis represents a distinct type of deposit. Three are marine and one is lacustrine. Sample 454 is a calcareous ooze from a mud-bank in Florida Bay, deposited in water less than a meter deep. Sample 418 is a greenish gray mud from the Santa Barbara Channel, California, in water 580 meters in depth. Sample 477 is a gray mud from Neuse River at the southwest end of Pamlico Sound, in 7 meters of water. Sample 119 is an algal deposit from Mud Lake, 30 kilometers northeast of Ocala, Florida, in water less than 20 centimeters deep.

The marine samples contain about 5 per cent of organic matter and on distillation produce about 2 gallons of oil per ton. Sample 119 from the algal lake probably is a mother rock of a rich oil shale. It is more than one-half organic matter and yields a distillate of 28 gallons of oil

per ton. Sample 418 from the Channel Islands region of California contains remains of pelagic life and probably was deposited under conditions similar to those in which the source beds of the oil fields of the Los Angeles basin were formed. The organic matter in sample 477 from Pamlico Sound is probably strongly influenced by material draining from adjacent large swamps. Sample 454 is a limestone-forming deposit.

Extraction with CCl_4.—The first step in our analyses of the organic content of the sediments was extraction with an organic solvent in order to remove the fatty and oily constituents. Carbon tetrachloride, because of its uninflammability, its relative cheapness, and the high degree of purity in which it may be obtained, was selected as the solvent. Technical CCl_4 purified by one distillation was used. It contained only 0.02 per cent CS_2 and less than 1 part per 100,000 of volatile constituents.

Before the sediments could be extracted it was necessary to dry them. Oxidation was inhibited by drying the samples as rapidly and at as low a temperature as possible. Preliminary experiments showed that evaporation under reduced pressure at room temperature was too slow to be practicable. The procedure adopted was to dry the sediments in a long tunnel through which warm air at a temperature of about 60° C. was passed. The samples were spread on trays in a layer about 3 centimeters thick and were dried until they ceased to appear plastic. The quantity of water lost was enormous. Sample 119, evidently a colloidal gel, lost more than 99 per cent in weight; No. 477, from Pamlico Sound, lost more than 80 per cent; and No. 418, from the Channel Islands, more than 65 per cent. After drying, they were ground in a roll grinder until all particles passed a 20-mesh screen (maximum diameter about 1 millimeter).

In order to extract large quantities of sediment it was necessary to devise a special extractor. This consisted of a 5-gallon can fitted with a removable top. Suitable pyrex tubes and cork stoppers connected the can, at the bottom, with a 5-liter distilling flask, and at the top with a reflux condenser, which also was in connection with the 5-liter flask. A mixture of sodium silicate and barium sulphate was applied to the joints to prevent escape of solvent. Carbon tetrachloride was placed in the system and the sediments were extracted continuously until the extract coming from the sediment was colorless. This ordinarily required about 30 hours. The can was half filled with sediment and could accommodate 10 kilograms. About five runs could be made before the CCl_4 began to attack the cans.

Method of analysis.—The method of analysis adopted is the common procedure used for ether extracts. The material was saponified, the fatty acids were separated from the saponifiable fraction, and the pigments, sterols, and hydrocarbons from the unsaponifiable part. The presence of relatively large amounts of free sulphur in all the extracts necessitated preliminary crystallizations from benzene and chloroform to remove the sulphur. While removing the solvents, the writers tried not to overheat the mixtures or to continue the evaporation longer than necessary. In this manner loss of liquid parts of the extracts was minimized. Oxidation was inhibited by driving off the final traces of the solvent in an atmosphere of CO_2. Similarly the extracts, when not being studied, were stored in an atmosphere of CO_2.

SAMPLE 454 FROM FLORIDA BAY

Preliminary treatment.—The CCl_4 extract from 30.6 kilograms of dried sediment 454 from Florida Bay was filtered and distilled as much as possible to drive off the solvent, the temperature being kept below 80° C. While still warm the residue was dried with a slow stream of CO_2. The yield was 20.0 grams, or 65 parts per 100,000. The dried extract was treated with 95 per cent ethyl alcohol and decanted, the action being repeated until the alcoholic solution was practically colorless. The alcohol insoluble part was similarly treated repeatedly with ether. The residue left after the action of these two solvents was soluble in warm benzene. On concentration, yellow crystals of sulphur, melting at 115°-115.6° C., crystallized from the benzene solution. These crystals, most of which were monoclinic, were readily soluble in CS_2 and warm chloroform. Cooled to room temperature, the alcohol and ether solutions formed yellow amorphous precipitates. The solutions were combined, the solvents distilled off, and the residue taken up in warm chloroform, from which repeated crystallizations produced more crystalline sulphur. The total yield of sulphur was 6.76 grams, or 22 parts per 100,000.

The chloroform was distilled off and the residue saponified with alcoholic potash. After the resulting mixture had been concentrated and cooled, it was extracted repeatedly with ether to remove the unsaponifiables, and was saponified again to insure completeness of the action. However, it was found that the first saponification had been sufficient, as no additional saponifiable material was procured.

Examination of the saponifiables.—The saponifiable part was diluted with ether and acidified gradually in order to prevent the formation of H_2S. Analysis of the ether layer showed the presence of two fatty acids, each in 1 part per 100,000. One evidently was melissic acid, ($C_{30}H_{60}O_2$),

as it melted at 90° C. and its impure lead salt at 115°. The other, characterized by a sweaty odor and melting at $-6°$, apparently was caproic acid ($C_6H_{12}O_2$). Addition of lead acetate to the ether-insoluble part brought down a heavy precipitate of lead sulphide, indicating the presence of organic sulphur compounds in the original extract. The amount of these compounds was 9.3 grams, or 30 parts per 100,000.

Examination of unsaponifiables.—The ether solution containing the unsaponifiables was washed free from alkali, dried with anhydrous sodium sulphate, filtered, and freed from ether. Treatment with warm chloroform yielded 0.88 grams of crystalline sulphur. This sulphur evidently came from the destruction of organic sulphur compounds during saponification, and is included in the estimate of 9.3 grams for those compounds. After the removal of the sulphur, the chloroform was driven off, the solution taken up with petroleum ether (boiling point 30°-60°), and refluxed with animal charcoal to take out the pigments. The petroleum ether was distilled off, and the residue, a reddish solid, was acetylated with acetic anhydride under reflux condenser in order to separate the higher alcohols from the hydrocarbons. While still warm, the acetylated mass was poured into boiling water. After the solution had cooled to room temperature, a dark solid floated on its surface, but no solids were present within it. This indicated the absence of higher aliphatic alcohols. The solid substance that floated on the mixture was washed free from acetic acid, taken up in petroleum ether, and extracted with absolute alcohol to separate it from the solution. This substance probably was phytosterol acetate, as it melted at 122° C. The amount obtained was 0.05 grams, or 2 parts per million.

Neutralization of the acetic solution with sodium hydroxide and evaporation to dryness gave sodium acetate, a further indication of the absence of higher alcohols. The residue was taken up in petroleum ether, from which repeated crystallizations produced an almost colorless waxy solid, melting at 62° C. This probably was a paraffine, possibly $C_{30}H_{62}$. Concentration of the petroleum ether solution to dryness produced a reddish yellow waxy solid, melting with decomposition at 62°-64°. It is probably composed largely of the same substance as was obtained from the first concentrations of the petroleum ether solution. The combined weight of the paraffinaceous materials was 1.78 grams, or 6 parts per 100,000. The pigments were recovered from the charcoal by refluxing successively with petroleum ether and carbon bisulphide. The petroleum ether was removed, the residue taken up in CS_2, combined with the other CS_2 part, and passed through a column of tightly packed calcium car-

bonate, which absorbed most of the color. This suggests that the pigments are of a carotinoid nature. By difference, the amount of pigments was estimated to be 1.38 grams, or 5 parts per 100,000. Table I presents a summary of the analysis.

TABLE I

SUMMARY OF CCl_4 EXTRACTS OF SEDIMENTS

SAMPLE 454—FLORIDA BAY

Substance	*Grams*	*Per Cent Extract*	*Parts per 100,000*
Weight of sediment	30,600.00		
Amount extracted	20.0		65
Free sulphur	6.76	33.8	22
Caproic acid ($C_6H_{12}O_2$)	.36	1.8	1
Melissic acid ($C_{30}H_{60}O_2$)	.38	1.9	1
Sulphur compounds	9.3	46.5	30
Pigments	1.37	6.9	5
Phytosterol	.05	.3	0.2
Paraffines	1.78	8.9	6

SAMPLE 418—CHANNEL ISLANDS, CALIFORNIA

Substance	*Grams*	*Per Cent Extract*	*Parts per 100,000*
Weight of sediment	6,440.00		
Amount extracted	5.6		87
Free sulphur	3.3	58.9	51
Montanic ($C_{28}H_{56}O_2$) and melissic ($C_{30}H_{60}O_2$) acids	.31	5.6	5
Sulphur compounds and pigments	.5	8.9	8
Cholesterol	Trace		
Paraffines	1.5	26.8	23

SAMPLE 418 FROM CHANNEL ISLANDS REGION, CALIFORNIA

Sample 418, from the Channel Islands region, was analyzed in essentially the same manner as was sample 454. Only 6.44 kilograms were available for extraction. This smallness of the quantity was due to the difficulty in collecting in deep water and to the high content of water in the fresh sediment. The yield was 5.6 grams, or 87 parts per 100,000. The amount of free sulphur was 3.3 grams, or 51 parts per 100,000. This is nearly 60 per cent of the extract. The fatty acid fraction melted at 86°-89° C. and evidently was a mixture of melissic ($C_{30}H_{60}O_2$) and montanic ($C_{28}H_{56}O_2$) acids, which melt at 91° and 83° respectively. The sulphur compounds were not separated and are included in the estimate of pigments, which was obtained by difference. The pigments probably

contained chlorophyl, as magnesium was found in the ash resulting from ignition of the residue recovered from the animal charcoal.

The residue after removal of the pigments was a reddish brown solid. The washings from acetylation were not turbid, indicating the absence of higher aliphatic alcohols. A few reddish crystals, melting at 114°, probably consisting of cholesterol acetate, were obtained from the methyl alcohol solution of the residue from acetylation. Following the removal of the sterols, the methyl alcohol solution was cooled in water and chlorinated in sunlight. The excess of chlorine was removed by bubbling dried air through the solution, which caused hydrochloric acid fumes to be driven off. The chlorinated solution was concentrated by distilling off the alcohol, water was added, and the mixture heated. A reddish yellow solid, insoluble in water, melting at 93° C., and giving a positive test for chlorine, was obtained. This indicated the formation of substitution products, and demonstrated the presence of saturated hydrocarbons. The amount of paraffines present was 1.5 grams, or 23 parts per 100,000. A summary of the analysis is given in Table I.

SAMPLE 477 FROM PAMLICO SOUND

In analyzing sample 477 from Pamlico Sound, the writers modified the procedure. From 11.66 kilograms of sediment, 17.0 grams of extract, or 146 parts per 100,000 was obtained. After the removal of the free sulphur, which constituted 12.1 grams, or 71.2 per cent of the extract, the solution was distilled free of solvents and taken up in hot alcohol. On cooling, it formed a waxy mass, which melted at 73°-76° C. This mass was separated from the solution and saponified with alcoholic potash. The resulting soap, on being acidified with concentrated hydrochloric acid in dilute alcohol, formed a fatty acid having the same melting point, 73°-76°, as the mass which separated from the original extract. The identity of melting points before and after saponification seems to indicate that the fatty acid occurs in the free state rather than as a soluble soap or fat. The melting point approximates cerotic acid, which melts at 76°-82° C. The quantity of fatty acid recovered was 0.69 gram, or 6 parts per 100,000.

The alcoholic solution from which the fatty acid had been removed was distilled free of solvent, taken up in petroleum ether, and refluxed with animal charcoal. Dark green pigments to the extent of 0.55 gram, or 5 parts per 100,000, were recovered from the charcoal by successive treatment with warm alcohol, ether, acetone, and chloroform. After removal of the pigments, the petroleum ether was driven off, and the

residue saponified with sodium ethylate. The residue from the ether-soluble part of the saponified mixture consisted of only a few milligrams of a green solid, which indicates that solid hydrocarbons were present in very small quantities. From the dark red ether-insoluble part, a dark, lustrous, pitch-like precipitate formed as the solution cooled. This pitch was fairly soluble in warm benzene. It softened at 60° C. and melted at about 80°. Approximately 3.5 grams, or 30 parts per 100,000 were recovered. As this residue represents the saponifiable part of the extract after the fatty acids had been removed, it probably consisted essentially of sulphur compounds. A summary of the analysis is shown in Table II.

TABLE II

SUMMARY OF CCl_4 EXTRACTS OF SEDIMENTS

SAMPLE 477

Substance	*Grams*	*Per Cent Extract*	*Parts per 100,000*
Weight of sediment	11,660.00		
Amount extracted	17.0		146
Free sulphur	12.1	71.2	104
Cerotic acid ($C_{26}H_{52}O_2$)	.69	4.1	6
Sulphur compounds	3.5	20.6	30
Pigments	.55	3.2	5
Sterols	0.00	0.0	0
Paraffines		Trace	
Loss in handling	.16	0.9	1

SAMPLE 119

Substance	*Grams*	*Per Cent Extract*	*Parts per 100,000*
Weight of sediment	10,260.00		
Amount extracted	24.4		238
Free sulphur	9.9	40.6	97
Cerotic acid	1.6	6.5	16
Sulphur compounds	3.7	15.2	36
Pigments	0.4	1.6	4
Phytosterol	1.6	6.5	16
Cholesterol	0.2	0.8	2
Paraffines	7.0	28.7	68

SAMPLE 119 FROM FLORIDA ALGAL LAKE

Sample 119, presumably a mother rock of an oil shale, yielded 24.4 grams, or 238 parts per 100,000, from 10.26 kilograms of sediment. The yield of free sulphur was 9.9 grams, or 97 parts per 100,000. The residue, after removal of the sulphur, was taken up in hot alcohol, and on cooling

separated into a greenish yellow mass and red oily globules. Cooled to room temperature, the globules formed a brittle pitch, which when separated weighed 1.6 grams. The pigments were separated by the method of Willstaetter and Stoll.[1] The mucilaginous mass and the pitch were saponified separately with 30 per cent methyl alcoholic potash under reflux condenser for a short time. The resulting mixtures were cooled, washed into separatory funnels, acidified with 20 per cent hydrochloric acid, shaken with ether, neutralized with NH_4OH until the aqueous layer acquired a faint bluish tint, shaken with more ether, and washed with water to remove the methyl alcohol. Approximately 0.3 gram, or 3 parts per 100,000, of green pigment and 0.1 gram of brown were obtained.

After removal of the pigments the mixtures were combined, saponified with normal sodium ethylate, distilled free of alcohol, and extracted with ether. From the brown ether-insoluble part, 5.3 grams of solids were obtained. Of this, 1.6 grams, or 16 parts per 100,000, were cerotic acid, $C_{26}H_{52}O_2$. The remainder consisted essentially of sulphur compounds and contained a small amount of phosphorus. This suggested the presence of lecithins, but no nitrogen was found. The red ether-soluble part yielded 8.8 grams of brittle pitch, which, when dissolved in a large volume of alcohol and treated with 1 per cent digitonin, yielded a precipitate weighing 2.7 grams. As 0.9 gram of digitonin was used, 1.8 grams, or 18 parts per 100,000, of sterols were present. After the digitonin had been removed by boiling the precipitate in xylene and filtering, the sterols were taken up in CS_2, treated with bromine to form dibromides, and dissolved in a mixture of ether and glacial acetic acid to separate the cholesterol from phytosterol. Phytosterol was eight times more plentiful than cholesterol.

After the removal of the sterols from the unsaponifiable part, the mixture was distilled free of solvent, taken up in CCl_4, brominated, stoppered, and allowed to stand in the sun. Profuse fumes of HBr were liberated by blowing breath over the solution, thus indicating the formation of substitution products and demonstrating the presence of saturated hydrocarbons. After the brominated mixture had been concentrated, it formed a brownish red amorphous precipitate, representing the saturated hydrocarbons, and a small amount of red greasy fluid, probably consisting of brominated unsaturated hydrocarbons. A summary of the analysis is shown in Table II.

[1]Richard Willstaetter and Arthur Stoll, *Investigations on Chlorophyll*, translated by F. M. Schertz and A. R. Merz (Scientific Printing Company, 1928), p. 88.

INTERPRETATION OF ANALYSES

ABSENCE OF PETROLEUM IN RECENT SEDIMENTS

No liquid hydrocarbons were observed in any of the extracts of these, the sediments richest in organic matter, found in our survey of practically the entire world. If any petroleum had been present in these deposits it would have been extracted by carbon tetrachloride and should have been noticed in the extracts. Yet, all the material extracted was solid. One would expect low-boiling hydrocarbons to evaporate while the solvent was being driven off, but the higher-boiling liquid hydrocarbons, which are normal constituents of petroleum, if they had been present, would not have been completely driven off.

To test the reliability of this inference, two California crude oils, of 27° and 20° Bé. respectively, were dissolved in CCl_4 in the same concentration and treated in the same manner as the extracts of the four sediments described in this paper. The residue after removing the CCl_4 from these crude oils was liquid, although the lighter oil lost 20 per cent in weight and the heavier oil, 4 per cent.

Petroleum is a mixture of many members of the paraffine and olefine series, as well as of other hydrocarbon and related compounds. Consequently, one would not expect the CCl_4 extract of a petroleum to consist of a solid, most of which melted at a constant temperature. Yet, nearly all the hydrocarbon part of sample 454 melts at a temperature of 62° C. In fact, except for their content of paraffines, these extracts do not resemble petroleum.

It is conceivable that some liquid hydrocarbons could have been lost during removal of the solvent, but the quantity, if any, must have been very small. The fact that the material extracted by CCl_4 was solid indicates that if petroleum had been present, it must have been a heavy oil. The heavy crude oil of 20° Bé. was liquid after it had undergone the same treatment as the extracts from the sediments. Yet it lost only 4 per cent during this process. A higher proportionate loss would not be expected from a petroleum that gave a solid residue.

Sample 119, the mother rock of a future oil shale, contained 68 parts per 100,000 of paraffinaceous substances. As these were solid, it follows from analogy with the experiment with crude oils that less than 4 per cent of the liquid compounds might have evaporated during the process of extraction. This means that less than 3 parts per 100,000 could have been lost from this sample. The three marine sediments have much lower maximum estimates. Sample 418 might have lost 1 part per

100,000; sample 454, 0.3 part; and sample 477, nothing. However, nothing in the analyses indicates the presence of liquid hydrocarbons, and the presumption is that none was present. Consequently, it must be inferred that petroleum probably does not occur in sediments at the time of their accumulation, and if it is present, it is in very small amounts, certainly less than 3 parts per 100,000, a quantity too small to be of importance in the formation of commercial oil pools.

DISCUSSION OF THE CONSTITUENTS OF THE EXTRACT

Solid hydrocarbons.—Paraffines are reported in significant quantities from all the sediments except sample 477 from Pamlico Sound. The paraffine fraction, however, may include wax-like substances. One would expect wax-like materials present in the sediment to be soluble to a certain extent in carbon tetrachloride; consequently, higher alcohols resulting from saponification of the waxes should have been detected by the analyses, but none except sterols was found. However, if any wax or wax-like substance that was extracted by carbon tetrachloride resisted saponification and acetylation, it would be included in the part reported as paraffine. We are inclined to regard the high figure of 68 parts of paraffine per 100,000 from sample 119 as in part probably representing wax or wax-like substances, which are known to be present in algal deposits of the type it represents. It is also possible that the marine sediments contain similar waxes. Consequently the figures for the paraffine part can only be regarded as the maximum value for the content of paraffine. The actual amount perhaps is lower. However, the analyses indicate that some paraffine is present, from which it is to be inferred that some normal components of petroleum may be present in fresh deposits.

Fatty acids.—Fatty acids are normal constituents of the sediments. They occur in a concentration ranging from 2 to 6 parts per 100,000 in the marine deposits, and a concentration of 16 parts per 100,000 in the algal sample. With the exception of caproic acid ($C_6H_{12}O_2$) observed in the limestone-forming sediment from Florida Bay, the acids in all the samples are similar. They consist essentially of three acids, cerotic ($C_{26}H_{52}O_2$), montanic ($C_{28}H_{56}O_2$), and melissic ($C_{30}H_{60}O_2$). In the only sample for which we have data on the manner of occurrence of the fatty acid (sample 477), the evidence indicated that the acid occurred in the sediment in the free state rather than as a soap or fat. In sample 454 from Florida Bay, both a fatty acid and what appears to be a paraffine

have the same chemical radical, $C_{30}H_{60}$. Whether this is a coincidence or is of genetic importance is not certain.

The content of fatty acid in the sediments may be greater than the figures given, as compounds such as calcium and magnesium soaps would not be soluble in CCl_4, but would remain in the sediment. In view of the equilibrium constants of such soaps it is well within reason to expect some of the fatty acid to occur in such a manner. It is hoped later to ascertain the amounts of such types of compounds.

The sum of the fatty acids and hydrocarbons in the marine deposits forms about 0.04 per cent of the sediment. This is less than 1 per cent of the organic content and seems inadequate to account for all the petroleum that might be generated from a source bed. Presumably some of the remaining 99 per cent of the organic matter must contribute to the formation of oil.

Organic sulphur compounds.—Organic sulphur compounds occur in about 30 parts per 100,000, except in sample 418, in which pigments and sulphur compounds together amount to only 8 parts per 100,000. Nothing is known of the nature of these sulphur compounds, as it was impracticable to analyze them further. The quantity of organic sulphur compounds present in the sediment is probably greater than that indicated by the analysis, as some probably would not have been dissolved by carbon tetrachloride.

Pigments.—Pigments are present in all samples in about 5 parts per 100,000. Practically no attempt was made to identify the pigments, but in sample 454, from Florida Bay, they seem to be of a carotinoid nature and in the sample from the algal lake they are three-fourths green pigment and one-fourth brown pigment.

Sterols.—Small amounts of sterols were present in all the samples. The chief significance of these compounds is that they give clues as to the animal or vegetable origin of the organic matter. Phytosterol is a normal component of plants, and cholesterol, of animals. Samples 454 from Florida Bay and 119 from the algal lake contain phytosterol, which indicates the presence of organic matter of vegetable origin. Sample 418, from the Channel Islands of California, contains cholesterol, which points to an animal origin of some of the organic matter. This is probably due to *Foraminifera.*

Sulphur.—Free sulphur[1] is a common constituent of all the samples. It occurs in quantities ranging from 22 to 104 parts per 100,000. As it

[1]P. D. Trask and C. C. Wu, "Free Sulphur in Recent Sediments," *Bull. Geol. Soc. Amer.*, Vol. 41 (1930), pp. 89-90.

was recovered directly from the CCl_4 extract, it is an original constituent of the deposits, but its initial concentration in the sediments may be lower than the figures given, as some sulphur may have been formed by oxidation of sulphur compounds during drying. Microscopical examination of some of the samples from Florida Bay demonstrated the presence of minute grains of a yellow, waxy substance having a refractive index much higher than 1.74. These grains probably are sulphur.

As the four sediments analyzed represent widely different types of deposits, it is probable that free sulphur is a common minor constituent of many sediments.

ORIGIN AND ENVIRONMENT OF SOURCE SEDIMENTS OF PETROLEUM DEPOSITS[1]

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ABSTRACT

The writer presents three fundamental geochemical factors which are connected with the origin and environment of petroleum deposits, and from these factors outlines a new conception of the origin of petroleum. The first of these factors is the vast amount of humic acids that are made only in swampy regions where there is more sand than clay. The second factor is the actual origin of asphalt and hydrocarbons from humic acid in a Florida vandyke brown lime. The third factor shows how nature activates or energizes silicon- and carbon-containing materials so that they emit subatomic energy which produces chemical reactions at ordinary temperatures and pressures by means of specific hydrogen ions. The writer not only offers data showing how hydrocarbons may be synthesized from humic acids, but also offers the most rational means of concentration of huge quantities of these acids in certain regions of the world where oil fields are now found or may be expected to be found.

The writer has discovered three fundamental sets of geochemical facts which doubtless have had fundamental importance in connection with the origin of most, if not all, source sediments of petroleum deposits.

The first of these facts was published in this *Bulletin* under the title of "The Humic-Acid Origin of Asphalt.[3] The writer actually found asphaltum and a few other hydrocarbons which had been synthesized from humic acids along the coast of Florida since America was discovered. The environment of the discovery consisted of a small fresh-water lake with a small tributary swampy stream in which humic acids were evolved. The humic acids were precipitated by brackish water after seeping into the white sand along the near-by shore of the bay. The most of these precipitated humic acids, being near the surface of the clean overlying sand, were oxidized into vandyke brown (an azo-humic acid) which is remotely related to wurtzilite.

The location and nature of the asphalt and other hydrocarbons found in the Florida hardpan here mentioned, which was mined for its vandyke brown content, were such as to leave no doubt that hydrocar-

[1]Manuscript received by the editor, August 19, 1930.

[2]1531 West Thirty-Second Street. Introduced by W. P. Haseman.

[3]J. D. Haseman, *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 5, No. 1 (January-February, 1921), pp. 75-79.

bons have been synthesized by nature from humic acids. Hence this offers the most plausible and logical explanation of the origin of petroleum deposits yet propounded.

The second set of facts, which has been published[1] by the writer and is connected with the origin of source sediments and environments of petroleum deposits, proves that vast amounts of dark brown humic acids are produced only in and along sandy-margined swampy streams and swamps or lakes, that is, in swampy regions where sand is more plentiful than clay. Such swamps are ordinarily rich in diatoms and if the humic acids happened to be precipitated locally instead of flowing a considerable distance, naturally many diatoms would be mixed in the sediments.

The Okefenokee Swamp of Georgia and the Rio Negro of Brazil are typical examples of humic acid-producing environments. Under such conditions the decay of plants is quite different from that in muddy swamps like many of those along the lower Mississippi. There is no doubt that the presence of sand in such regions is directly connected with the geochemical production of large amounts of humic acids. And azo-humic acids dissolve sand and form azo-silico-humic acids, which also have a fundamental bearing on nature's synthesis of some of our fundamental food crops.

The third set of facts having a bearing on the origin of source sediments of petroleum was published under the title of "The Alleged Catalytic Action of Fuller's Earth and Coloring Matters in Oils"[2] and in a later paper in the same journal entitled "The Nature of Catalytic Actions."[3] These papers show how nature activated fuller's earth; and how fuller's earth liberates sub-atomic energy that forms specific hydrogen ions that take direct part in decolorizing neutral oils. In fact, the writer is convinced that all true catalytic actions, which deal with oxidation and reduction and hydrolysis and dehydrolysis, are consummated by the catalyzers liberating sub-atomic or electronic energy which either assumes the form of specific hydrogen ions or produces specific hydrogen ions from moisture at ordinary living temperatures and pressures.

Silicon and carbon in certain chemical and physical states are the chief liberators of sub-atomic energy which produce almost all catalytic actions within the range of living temperatures and pressures. Nature can and does activate or energize both silicon and carbon in more than one way. Nature utilizes carbon dioxide, alum sulphate, azo-silico-

[1] J. D. Haseman, *op. cit.* Also, "Some Factors of Geographical Distribution in South America," New York *Acad. Sci.*, Vol. XXII (May, 1912), pp. 9-112.

[2] *Idem, Jour. Phys. Chem.* (October, 1929), pp. 1514-27.

[3] *Ibid.* (1930).

humic acids, and sulphuric acid from marcasite or pyrites in activating or energizing fuller's earth. Micro-organisms, or more probably their enzymes, which are energized carbon material, doubtless had some part in the production of both azo-silico-humic acids and sulphuric acid, which are connected with the activation of fuller's earth in the region of the underground water levels.

The regions of vast humic acid-producing swamps are and have been more or less parallel with old shore lines. They are ordinarily a considerable distance from both the old igneous rocks and old sandstones of the continents and the open seas or oceans in flat sandy regions. In order to collect or concentrate vast quantities of these humic acids in shales, sandstones, or limestones, the humic acids from these swamps could and did flow and seep to brackish or salt water in shallow, more or less land-locked seas. The salt water precipitated the humic acids which settled in the sediments, making limestone, shale, or sandstone. These precipitated humic acids were not only connected with the source of petroleum, but also affected the porosity of the rocks, especially after being synthesized into petroleum.

As the shore lines changed by elevations and subsidences of the continental shelves, the location of humic acid-producing swamps and humic acid-concentrating salty seas would change; but they would always be more or less parallel with the old shore lines just as are most of the known oil fields. Naturally small local fresh-water swamps or lakes, like some of the glacial peat-bog lakes, could have been so located that salt water could have seeped into them and precipitated the humic acids; or humic acids could have been concentrated locally, like our western dopplerite; or humic acids could have been precipitated electro-chemically, as were some of the Georgia and Florida hardpans; but none of these suppositions would meet the conditions of most of the known oil fields.

A few writers have noted that geochemical changes in sedimentary strata are ordinarily greater along fault lines, anticlines, monoclines, et cetera, regardless of whether they contain oil or not. This may have considerable importance in connection with the synthesis of petroleum; because it was equally as important to produce special geochemical conditions in the original sediments for petroleum production as to deposit proper source material or to produce a trap to retain the oil after it was synthesized.

The writer has produced the red and yellow coloring matters of oils from humic acids and changed them into asphalt. They can be hydrogenated and changed into other hydrocarbons. However, even though

there are many available data on hydrogenation of carbonaceous materials, the exact process nature used is unknown, but it evidently worked at low temperatures like enzymes and activated carbon and silicon materials. In fact, the decolorizing of oils by fuller's earth is a form of hydrogenation. There is no doubt that nature's exact geochemical process did exist in several local places in the Florida vandyke brown mine and did produce asphalt from humic acids.

The elements of time, temperature, pressure, absence of air and light, sulphuric acid from both pyrites and sulphates, with or without micro-organisms and enzymes, salts in salt water, alum sulphate, carbon dioxide, iron- and calcium-containing materials, silica, and activated silica- and carbon-containing materials probably were more or less important factors in the steps of the synthesis of petroleum. Activated silica- and carbon-including enzymes very probably produced most of the specific hydrogen ions utilized by nature to synthesize petroleum. Methane- and sulphur-containing material may also have been utilized; but doubtless specific nascent hydrogen ions, however produced, were used by nature in the synthesis of petroleum.

If the foregoing viewpoint of the origin and the environment of the source material and its deposition is essentially correct, geologists can locate fairly accurately the regions of past humic acid-producing swamps, and with a less degree of certainty the regions where humic acid was precipitated or concentrated principally by salt water. But until our present state of geochemical information is materially augmented, the writer fails to understand how the geologist can determine the regions where nature also laid down special geochemical conditions for the later production of specific hydrogen ions to be used for the synthesis of petroleum from its source material.

SECONDARY SALT-DOME MATERIALS OF COASTAL PLAIN OF TEXAS AND LOUISIANA[1]

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ABSTRACT

Secondary materials consist of anhydrite (which is residual after salt leaching and which is the primary mineral of gypsum, calcite, and sulphur), gypsum, calcite, sulphur, and minor accessories such as galena and sphalerite. None of these represents original deposition. "Burned" cores of granular gypsum and coarse selenite have changed to satin-spar gypsum. Pseudo-lamination in anhydrite is illustrated. One replacement of selenite by sulphur is discussed and figured.

During the past 6 or 7 years the writer has examined casually and also in detail many cores and bit samples of salt-dome materials in the Coastal Plain of Texas and Louisiana. Among these have been many which are of somewhat general interest. The samples discussed herein are of interest chiefly because of the bearing they have on the origin of secondary salt-dome materials in general, and on sulphur in particular.

It is the writer's belief, as it has been the belief of many who have written on the subject, that the sequence of origin of the secondary materials is: (1) salt with an average of about 5 per cent of finely disseminated anhydrite; (2) solution through which the anhydrite is concentrated into anhydrite sand, and which may or may not later become massive anhydrite, depending probably on depth and pressure; (3) hydration of anhydrite to gypsum; (4) alteration of gypsum to limestone and sulphur, at which time the other secondary materials, such as galena, sphalerite, hauerite, and barite,[3] have been formed.

During the time required for the completion of this sequence to an appreciable quantity of secondary material, many structural changes

[1]Published with permission of the Gulf Production Company. Manuscript received by the editor, September 5, 1930. Since this paper was mailed to the editor the writer listened at Freeport, Texas, to a paper on dome materials by Levi S. Brown, of the University of Texas. This paper was discussed with him at that time. Mr. Brown's paper is excellent and its publication will advance greatly our knowledge of these materials.

[2]Geological department, Gulf Production Company.

[3]A chemical analysis by H. O. Nicholas of a core from 1,343-46 feet from the Gulf Refining Company's W. H. Stark No. 2 at Thibodaux, La Fourche Parish, Louisiana, shows 58 per cent $BaSO_4$ and 3.2 per cent $SrCO_3$. No $SrCO_4$ was present.

occur. As salt is removed through solution from the top of the dome, the cycle proceeds to the formation of an arch of secondary materials which, with continued solution, collapses. The collapse-breccia is re-cemented through a continuance of alteration of gypsum and anhydrite. With more solution more collapse occurs. The result is the limestone breccia so well known in the limestone caps above the coastal as well as interior domes. Except in a few domes where sedimentary limestones have been side-tracked as blocks in the upthrust of the salt, the writer is convinced that all of the dome limestone caps are of secondary origin, and except in exceedingly few domes no deep-seated limestones have been pushed ahead of the salt to form the present cap-rock series. In some of the coastal domes Oligocene limestones form part of the sedimentary series and have been mistaken for dome cap rock.

In these super-dome collapse-breccias the sequence of secondary materials may vary, as shown by drilling. At Sorrento dome, Ascension Parish, Louisiana, gypsum is commonly the first material encountered and is ordinarily underlain by Neogene fossiliferous shales and limestone fragments. As much as 100 feet of this type of material may be penetrated before the hard, porous, limestone breccia is reached. Arch collapse is even more demonstrable at Thibodaux dome, LaFourche Parish, Louisiana. At Thibodaux the higher part of the zone of collapse is only partly cemented, and found with the secondary dome materials is a mixture of Neocene shale, sand, and gravel from above. Thibodaux was stripped by erosion at a much later date than was Sorrento. At Thibodaux the breccia in individual cores consists of shale, sand, gypsum, sulphur, limestone, and probably other secondary materials. The brecciated character is evident. Cementing increases with depth. The cementing is chiefly by calcium carbonate, and can be traced from single rhombs of calcite to typical limestone cap. Collapse is probably continuous or at least intermittantly continuous, depending on the rapidity of solution and the periodicity of salt intrusion. The gouge zone of Neogene shales, so commonly found extending up the flanks and over the tops of many of the domes, has not been found at Thibodaux. Collapse on a more deeply seated type of dome can be illustrated by the Port Barre dome, St. Landry Parish, Louisiana. Careful examination of cores from this dome, especially on the north and west sides, demonstrates collapse. Faulting is associated with collapse of the super-dome arch, although such faulting is ordinarily difficult to prove, because of the character of the beds above, unless they have been well cored.

The anhydrite zone extending down the flanks of the coastal domes is considered by the writer to be the result of the concentration of the

anhydrite of the salt through solution. The writer has discussed this with many of the students of coastal salt domes, and has found none who disagrees with this conclusion in principle, although a few disagree in extent. There can be little question concerning the principle. The writer contends that the extent to which this solution could occur is governed by the size of the salt column. Complete solution through the salt column, thereby separating the salt into an upper and a lower part, would be the horizontal limit of solution.

The development of Barber's Hill, Chambers County, Texas, has beautifully demonstrated the mushroom structure of the dome. In this connection it is interesting to note that the water from the Humphreys Corporation's T. H. McLean No. 1, from 5,360 feet, contained 6.6 per cent chlorine, although the water from the Rexall Smith No. 1, nearly 200 feet farther from the dome, from 2,137 feet, contained 15.7 per cent chlorine, or was approximately saturated. The Humphreys well was drilled through 298 feet of rock salt. The Rexall well is just outside the outer edge of the mushroom. If there is any artesian circulation of the 6.6 per cent water at approximately 5,000 feet, and it seems probable that there is, it would migrate in and upward along the periphery of the salt, and become saturated with sodium chloride a relatively short distance above the 5,000-foot level. It would continue to migrate upward, but would not remove any more salt because of saturation. The saturated water from the Rexall well at the outer edge of the mushroom would be this water from lower depths. Through such undermining by solution it seems possible that some, if not all, of the coastal mushroom domes are the result of the removal of large quantities of deep-seated peripheral salt.

The presence of such deep-seated peripheral salt solution is the cause of the well known structures found around many of the coastal and interior salt domes, such as extensive down-thrown blocks inside toward the dome, rim synclines, brecciated zones of caved material in which the sequence of formations is not normal, as well as the complication of both radial and tangential faulting. The result in connection with oil traps is apparent.

Salt-dome structures will be discussed more comprehensively in a later paper. The sequence of formation of dome materials is here mentioned briefly as an introduction to the discussion to follow.

Several years ago, in the examination of cores from the early wells at Stark's dome, Calcasieu Parish, Louisiana, the writer found a core in which very finely laminated anhydrite was present, and which, on


A
1
A
B
C
C
E
D
2
B
A
A
B
C
3
4
A
B
C
D
E
5
6

PLATE 5

FIG. 1.—Satin-spar gypsum resulting from "burning" of selenite gypsum core. Near periphery of core. See Figure 4. About actual size. Gulf Production Company's Thomas Cavity No. 1, Fannett dome, Jefferson County, Texas. Depth, 1,272-1,273 feet.

FIG. 2.—Core showing finely granular gypsum (*C*) cut by vein of selenite gypsum (*E*). Clear selenite (*E*) has been partly displaced by sulphur (*A* and *B*). A sulphur veinlet at *D*. Magnification 1.1×. One inch in diameter from Figure 5. Same well as Figure 1. Depth, 1,366-1,372 feet.

FIG. 3.—Partly formed satin-spar gypsum (*A*) resulting from "burning" of finely granular gypsum (*B*). *A*, nearer periphery of core. Magnification, 1.23×. Same core as Figure 1.

FIG. 4.—Satin-spar gypsum (*A*) resulting from "burning" of selenite gypsum (*B*). Vein of finely granular gypsum present at *C*. *A*, nearest periphery of core. *B*, nearest center. Magnification, 1.2×. Same core as Figure 2.

FIG. 5.—Core showing finely granular gypsum (*B* and *C*) cut by vein of selenite gypsum (*E*). Almost complete displacement by sulphur (*A* and D). Magnification, 1.2×. Same core as Figure 2.

FIG. 6.—Laminated anhydrite formed by drilling and not by deposition. Magnification, 1.25×. Standard Oil Company's Industrial Lumber Company's Stark Dome No. 2, Calcasieu Parish, Louisiana. Depth, 1,672 feet.

casual examination, strongly suggested original bedding. A note was prepared for publication calling attention to the pseudo character of this material, but was never submitted for publication. Since then Bramlette's[1] paper has appeared. The pseudo-stratification of this anhydrite need not be discussed further. It is sufficient to state that the lamination is due to drilling, not to deposition. The fragments of steel scattered through the material are sufficient evidence of the pseudo character. No free sulphur was found in the laminated material (Plate 5, Fig. 6).

This fine pseudo-stratification is not to be confused with the pseudo-bedding commonly seen in anhydrite cores. The latter normally has the dip of the dome flank, and is ordinarily used to support the contention that an anhydrite bed has been pushed bodily over the dome. It is contended that this supposed bedding is a type of schistosity due to the well recognized high plasticity of anhydrite under temperatures and pressures very much less than necessary to develop this type of texture in other rock. However, it may have been formed at the times of upthrust of the salt mass when temperatures and pressures were somewhat elevated. After examination of much supposed bedding of this sort, the writer is convinced that it is not true bedding.

In this connection it may be worth mentioning that no places are known, as far as the writer is aware, where limestone rests directly on salt, although hundreds of places might be mentioned where no limestone is present, and gypsum or anhydrite is the only material present between the younger beds above and the salt. It seems strange that the sequence should be so dominantly limestone-anhydrite-salt if the limestone and anhydrite were material forced from the original salt series ahead of the salt.

"Burned" cores are ordinarily of interest. In fact, certain supporting evidence for the theory of volcanic origin of salt domes of the Coastal Plain was due to the study of burned cores. Figures 1, 3, and 4 (Plate 5) illustrate the effect of the burning of gypsum. Satin-spar gypsum has resulted from the "burning" of both selenite and finely granular gypsum. The selenite crystal (Fig. 3) was approximately 3 inches across. In none of this "burned" material was free sulphur found.

The laminated and "burned" material is believed sufficient to show that the free sulphur of Figures 2 and 5 is the result of neither actual drilling nor heating.

These figures show two sections of a core from the Gulf Production Company's Thomas Cavity No. 1 at Fannett dome, Jefferson County,

[1] N. M. Bramlette, "Pseudo-Stratification in Core Recoveries," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 12, No. 12 (December, 1928), pp. 1167-69.

Texas, from a depth of 1,366-1,372 feet. In this one place, at least, displacement of selenite by sulphur is considered to be demonstrated. *C* of Figure 2 and *B* and *C* of Figure 5 indicate finely granular gypsum. The material is fairly porous and the average length of the gypsum crystals is about a millimeter (this is about the size of the anhydrite crystals remaining after the leaching of a salt core). Scattered through the gypsum are many calcite crystals, euhedral to anhedral, having an average length of a millimeter or less. These calcite crystals are of the dog-tooth spar variety. Seemingly the granular gypsum is changing to calcium carbonate. Very little free sulphur was found in the granular gypsum. A few veinlets are present. The large selenite crystal at *E* in Figures 2 and 5 has been altered to sulphur at *A* and *B* in Figure 2 and at *D* in Figure 5. This sulphur as shown at *B* in Figure 2 and at *D* in Figure 5 is dendritically displacing the selenite.

In conclusion, these bits of evidence are offered as added proof of the sequence mentioned. This evidence is not due to mechanical causes during drilling. Other factors are important in the formation of secondary materials, such as temperature, character of dome waters, possibly bacteria, pressure, depth, and time. Time, depth, and pressure probably constitute the most important factors in the formation of secondary materials.

GEOLOGICAL NOTES

GLEN ROSE GAS PRODUCTION IN NORTHEAST TEXAS

The first wells in the Glen Rose formation of the Trinity in northeast Texas recently have been completed. The wells are located in the southwest part of the Bethany gas field, Panola County, Texas. The Natural Gas Production Company's Roquemore No. 8 is the discovery well. It was completed May 14, 1930, for an initial open flow of 8,000,000 cubic feet of gas and a closed pressure of 2,190 pounds.

A summary of the log, beginning with the top of the Lower Cretaceous at a depth of 2,250 feet, is as follows.

	Depth in Feet
Limestone	2,529
Gray shale streaked with sand and red shale	2,680
Limestone with shale breaks	3,123
Shale streaked with limestone	4,072
Anhydrite	4,092
Limestone	4,324
Anhydrite with breaks	4,635
Limestone	4,645
Gas at	(total depth) 4,645

A second test, 1,800 feet south of the discovery well and located on approximately the same contour, was completed on September 29, 1930, at 4,718 feet, in oölitic limestone. It had an open flow of 24,000,000 cubic feet with 400 pounds back pressure. The closed pressure was 2,215 pounds.

The closed pressures are nearly 10 per cent higher than normally expected at the depths where the wells were completed.

DUGALD GORDON

SHREVEPORT, LOUISIANA
October 9, 1930

REVIEWS AND NEW PUBLICATIONS

Simple Geological Structures. By John L. Platt and John Challinor. (D. Van Nostrand Company, New York; Thomas Murby and Company, London, 1930.) 56 pp. Illus. Price, $1.35 (3 s. 6 d.) net.

In the course of most geologic instruction, too little attention is commonly given to the expression of various geologic structures on maps, that is, on topographic surfaces. For that reason, manuals on map reading, provided they are adequate in scope, and dependable in statement, are always of interest to the teacher of geology.

Simple Geologic Structures, by John L. Platt and John Challinor, is a recent addition to the literature of this subject.

Unfortunately, at several points, the treatment of the subject is much too abbreviated. The following examples indicate the brevity of the treatment of important topics.

On page 11 reference is made to the principle of "V's" in relation to rock dip, but no diagrams are given, and no conclusions drawn. On page 13, contrast between true thickness and vertical thickness of dipping beds is noted, but there is no discussion of the limits of dip in which vertical thickness departs so slightly from true thickness as to be safely used without correction. On page 15, simple disconformity is not mentioned, in the discussion of unconformity. It is always wise to designate the items which can not be distinguished on maps as well as those that can. On pages 20-21, the lack of scale on the maps makes it uncertain how far the strike lines are being projected, but such projection for considerable distances is rarely possible. On pages 27-30, the discussion of faults omits all reference to faults in areas of horizontal rock, and makes no mention of strike faults with repetition of outcrop or failure to crop out. These faults are fully as important as those treated. The discussion of folds on pages 33-36 omits entirely all mention of the effect of pitch on the shape of the outcrop, in spite of the fact that pitching folds are more common than those with no pitch.

Still more unfortunate is the use of loose statements, that is, those which are not exactly accurate or complete. For instance, on pages 7-10 repeated reference is made to strike lines, each reference assuming uniformly dipping (unwarped) planes, though this is not specifically stated. Again on page 9 and on page 13 no account is taken of the dual usage of the word outcrop, which we commonly use (1) for area where specified rock is next beneath the surface soil, and (2) for the actual exposure. On page 23, the occurrence of valleys along faults is overemphasized. Perhaps the majority of faults show no such feature, and a few faults, where strongly silicified, crop out as ridges or reefs. On page 24, dip fault is defined as a fault the strike of which is parallel with the dip. The statement should be that its strike is parallel with the direction of dip, not with the dip. On page 27 appears a very misleading

statement to the effect that, inasmuch as faults cross the map in straight lines, they are vertical. As a matter of fact, in a region of only moderate dissection, mapped on a small scale, faults may depart as much as 20° or even 30° from the vertical, and still show no visible deviation from straight lines. Such a condition proves them to be dipping steeply, but not necessarily vertically. The same applies to dikes (p. 43).

On page 34, the statement is made that newer beds tend to crop out on higher ground. In general this is true, but no mention is made of the very important fact that in folded regions of much relief the *relative resistance* of beds becomes the controlling factor, the more resistant beds, old or young, making the higher areas, whether synclinal, anticlinal, or on the flanks of folds.

In general, the printing of the book is good, but the maps would have been more legible and less confusing with fewer formations and fewer contours.

In spite of the shortcomings to which attention has been called, the book should have a real place in teaching, though it is not likely to be widely used in this country, where manuals are available that are designed especially for use with our own United States Geological Survey maps.

C. L. DAKE

MISSOURI SCHOOL OF MINES
ROLLA, MISSOURI
October, 1930

RECENT PUBLICATIONS

ALASKA

"The Upper Cretaceous Floras of Alaska," by Arthur Hollick. "A Description of the Plant-Bearing Beds," by George C. Martin. *U. S. Geol. Survey Prof. Paper 159* (Supt. Documents, Washington, D. C.). 123 pp., 87 pls., 5 figs., 1 insert. Paper. Price, $0.80.

GENERAL

Geochemie der Erdöllagerstätten. By Karl Krejci. (Wilhelm Knapp, Halle (Saale), Germany, 1930.) 50 pp. Price, 5.50 R. M. (approx. $1.35).

Methods in Geological Surveying. By Edward Greenly and Howel Williams. (Thomas Murby and Company, 1 Fleet Lane, London, E. C. 4, England; D. Van Nostrand Company, 250 Fourth Avenue, New York, New York, 1930.) 420 pp., 81 figs., 3 pls. Price, 17 s. 6 d.

Contributions to Economic Geology. Part II—Mineral Fuels. Contains (A) "The Forsyth Coal Field, Rosebud, Treasure, and Big Horn Counties, Montana," by C. E. Dobbin; (B) "The Kevin-Sunburst Oil Field and Other Possibilities of Oil and Gas in the Sweetgrass Arch, Montana," by A. J. Collier; (C) "Geology and Coal Resources of the Meeker Quadrangle, Moffat and Rio Blanco Counties, Colorado," by E. T. Hancock and J. B. Eby; and (D) "Geology and Oil Resources Along the Southern Border of San Joaquin Valley, California," by H. W. Hoots. *U. S. Geol. Survey Bull. 812*. (Supt. Documents, Washington, D. C.) 338 pp., 48 pls. (including 9 maps). Paper. Price, $1.25.

The Oil Bulletin, Vol. 1, No. 1 (September, 1930). The official organ of the Victorian Oil Producers' Association, 422 Collins Street, Melbourne, Victoria, Australia. Price, per copy, 3d.

Sullivan Machinery Company, 400 North Michigan Avenue, Chicago, Illinois, has issued the following publications of interest to geologists.

"The Sullivan Type '10' Diamond Core Drill," *Bull. 85-L* (September, 1930). 4 pp.

"The Sullivan Type '50' Core Drill, *Bull. 85-M* (September, 1930). 8 pp., illus.

"Sullivan Core Drilling by Contract," *Bull. 139* (September, 1930). 12 pp., illus.

GEOPHYSICS

"Practical Geomagnetic Exploration with the Hotchkiss Superdip," by Noel H. Stearn. *Amer. Inst. Min. Met. Eng. Tech. Pub. 370* (New York, N. Y., October, 1930).

MADAGASCAR

"Gisements pétrolifères de Madagascar," by C. P. Nicolesco. *La Revue Pétrolifère* (Paris), September 6, 1930, pp. 1225-29, 1231, 1 map; September 13, 1930, pp. 1257-59, 1261-62, 2 figs.; September 20, 1930, pp. 1289-91, 1293-94.

MONTANA

U. S. Geol. Survey Bull. 822-A. By R. S. Knappen and G. F. Moulton. Geologic report covering an area of more than a thousand square miles in south-central Montana, including parts of Carbon, Big Horn, Yellowstone, and Stillwater counties. 70 pp., 6 illus. (Supt. Documents, Washington, D. C.) Price, $0.25.

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in the *Bulletin*, under the head of "Suggestions to Authors," a few brief directions and hints which are based on our reading of manuscripts submitted, or on questions from contributors. We shall be glad to receive queries which can be answered here anonymously for the benefit of all members. We invite attention, however, to our regular leaflet, *Preparation of Manuscripts*, copies of which may be obtained from our business manager, Box 1852, Tulsa, Oklahoma.

Illustrations.—Diagrams and pictures for manuscripts should be carefully selected to illustrate specific facts, to clarify the text, and not merely to serve as ornaments. Each illustration should be accompanied by a title, so that the reader of the article need not search through the text for the explanation.

Illustrations are usually designated as *figures* if they will cover no more than a full *Bulletin* page and they are called *plates* if they require sheets larger than a page of the *Bulletin*, that is, if they must appear as folded inserts. Plates should be avoided if possible, for they are much more expensive to publish than figures. Authors should draw their large maps and diagrams with lettering and thickness of lines of such size and character that these illustrations can be reduced to not larger than full-page size and still be legible. In some drawings we have noticed that letters are made large enough, but with lines too thin, to bear reduction. Always one should be careful to use letters and numbers so large that, after reduction, they will certainly not be less than $^1/_{50}$ inch, and preferably not less than $^1/_{40}$ inch, in height. Make the whole drawing at least twice the size of the reproduction in the *Bulletin*.

Having decided which illustrations are to be *figures* and which are to be *plates* (after every effort has been made to avoid *plates*), the author should be careful, in his text, to refer to figures as such and to plates as such. Thus "Figure 1" must not be referred to as "Plate 1."

As regards line drawings, the best are prepared in India ink on tracing cloth, but not on yellow tinted tracing paper. Brown-line or black-line Vandyke prints are satisfactory. Blue-line prints can be reproduced, but by a process somewhat different from that used for black, brown, or red-line figures. For this reason, black, brown, or red lines should never be used on blue-line prints. If numbers, letters, or additional lines must be added on a blue-line print, blue ink should be used.

F. H. L.

SAN ANTONIO MEETING, MARCH 19-21, 1931

The sixteenth annual meeting of the Association will be held at San Antonio, Texas, on March 19, 20, and 21, 1931. The Gunter Hotel has been selected as convention headquarters. Dr. Laurence Gould, geologist and second-in-command of the Byrd South Polar Expedition, will give the popular lecture on the night of March 19. This lecture will be illustrated by moving pictures made on the Antarctic expedition and will be held in the large municipal auditorium.

As is customary, the executive committee of the Association will have general supervision of the arrangements for the meeting and Dr. Lahee, third vice-president in charge of editorial work, is planning the technical program.

Most of the local arrangements, however, are the responsibility of the San Antonio Geological Society, an official section of the Association, on whose cordial invitation the meeting is being held in San Antonio. Dr. Semmes, president of the section, has announced the appointment of the following committees and chairmen.

General committee	D. R. Semmes
Program committee	Charles H. Row
Finance committee	H. H. Cooper
Reception committee	L. F. McCollum
Entertainment committee	I. K. Howeth
Trips committee	J. M. Dawson
Transportation committee	W. W. Kelley
Registration committee	E. H. Finch
Exhibits Committee	J. D. Hedley
Ladies' entertainment Committee	J. B. Whisenant
Publicity committee	R. F. Schoolfield
Golf committee	Don Danvers

Additional information will be printed from time to time and the customary notices will be sent to all members. It is particularly requested that members who plan to offer papers for presentation on the technical program notify Dr. Lahee, Box 953, Dallas, Texas, immediately, and send him abstracts and the completed manuscripts as early as possible.

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AT HOME AND ABROAD

EMPLOYMENT

The Association maintains an employment service at headquarters under the supervision of J. P. D. Hull, business manager.

This service is available to members who desire new positions and to companies and others who desire Association members as employees. All requests and information are handled confidentially and gratuitously.

To make this service of maximum value it is essential that members coöperate fully with Mr. Hull, especially concerning positions available to active and associate members.

H. H. Power, petroleum engineer, Gypsy Oil Company, Tulsa, and C. H. Pishny, of the Amerada Petroleum Corporation, Tulsa, presented a paper on "Effect of Proration on Decline of Potential Production and on Ultimate Recovery," before the petroleum division of the A. I. M. M. E., Tulsa, October 2.

Joseph E. Pogue, consulting engineer, New York City, has an article on "The High Cost of Gasoline Surplus" in the October 2 issue of the *Oil and Gas Journal*.

E. H. Finch, geologist for the Atlantic Oil Producing Company in charge of the San Antonio district, visited New York and the Atlantic refinery in Philadelphia in September, and spent several days at the U. S. Geological Survey in Washington, D. C., where he was formerly in charge of the mineral classification of the public lands.

W. D. Matthew, chairman of the department of paleontology at the University of California, Berkeley, died at San Francisco, September 24, 1930.

J. Versluys, 394 Franklenslag, The Hague, presented a paper on "Some Principles Governing the Choice of Length and Diameter of Tubing in Oil Wells," before the Tulsa meeting of the A. I. M. M. E., October 2.

C. V. Sidwell, Box 547, Seminole, Oklahoma, presented a paper before the A. I. M. M. E. meeting, Tulsa, October 2, on "Bottom Hole Pressures and Pressure Gradients in Flowing Wells."

C. P. Parsons, of the Halliburton Cementing Company, Duncan, Oklahoma, presented a paper on "Characteristics of Mud-Laden Fluids," before the meeting of the A. I. M. M. E. in Tulsa, October 2.

D. Glynn Jones has resumed his duties with the Anglo-Persian Oil Company, Ltd., after a period of deputation to the Iraq Petroleum Company,

Ltd. His address is in care of the Geological Department, Anglo-Persian Oil Company, Ltd., Masjid-i-Suleiman, Persian Gulf.

E. L. ESTABROOK, Pan-American Petroleum and Transport Company, New York City, presented a "Progress Report on Foreign Unitization," before the Tulsa meeting of the A. I. M. M. E., October 3.

H. C. GEORGE, of the University of Oklahoma, Norman, Oklahoma, presented a paper on "Repressuring and Initial Pressuring," before the A. I. M. M. E. at its Tulsa meeting, October 3.

JOSEPH JENSEN, chief petroleum engineer, Associated Oil Company, Los Angeles, California, and J. B. STEVENS, petroleum engineer, Associated Oil Company, Fellows, California, are the authors of a paper on "Water Invasion —McKittrick Oil Field—An Apparent Reversal of Normal Oil Field History." The paper is published in the October issue of *Mining and Metallurgy* and was presented before the A. I. M. M. E. at its Los Angeles meeting in October.

JOSEPH JENSEN, chief petroleum engineer, Associated Oil Company, Los Angeles, California, and F. W. HERTEL, petroleum engineer, Associated Oil Company, Ventura, California, presented a paper on "Development Program in a Part of the Ventura Avenue Oil Field," before the Los Angeles meeting of the A. I. M. M. E., in October. The paper appears in the October issue of *Mining and Metallurgy.*

JOSEPH E. POGUE, consulting engineer, 42 West 12th Street, New York City, presented a paper on "Place of Unit Operation in Adjusting United States Petroleum to World Markets," before the Tulsa meeting of the A. I. M. M. E., October 3.

At the monthly meeting of the Shreveport Geological Society, October 3, the following officers were elected for the ensuing year: president, S. C. STATHERS, Standard Oil Company; vice-president, C. L. MOODY, Ohio Oil Company; and secretary-treasurer, G. W. SCHNEIDER, The Texas Company.

B. COLEMAN RENICK, of the Vacuum Oil Company, San Antonio, Texas, has an article on "The Petrology and Geology of a Portion of Malheur County, Oregon," in the August-September issue of *The Journal of Geology.*

H. D. EASTON, petroleum geologist, Shreveport, Louisiana, has an article on "Composition of Zwolle Marl—Best Methods for Completing Wells in New Producing Formation," in the September 26 issue of *The Oil Weekly.*

GERHARDT G. SENFTLEBEN, assistant to EDWARD BLOESCH, consulting geologist, Tulsa, Oklahoma, returned to Tulsa in October, after spending the summer in Switzerland.

DORSEY HAGER, Wichita Club, Wichita, Kansas, has an article on "Hugoton Area Has Vast Gas Reserve," in the October 2 issue of the *Oil and Gas Journal.*

At the September meeting of the San Antonio Section of the Association, J. S. HUDNALL gave a paper on the "Surface Structure of Kendall County and

Vicinity," and JOSEPH M. DAWSON presented a paper on the "Subsurface Structure and Stratigraphy of Kendall, Kerr, and Bandera Counties." At the meeting of October 6, L. W. NACNAUGHTON led a discussion on the structure and correlation of the Claiborne group in Texas and Louisiana. L. W. STEPHENSON, of the U. S. Geological Survey, and Miss ALVA C. ELLISOR, of the Humble Oil and Refining Company, participated.

J. MARVIN WELLER, of the Illinois State Geological Survey, Urbana, Illinois, is the author of an article in the September number of *Journal of Paleontology*, on "Siliceous Sponge Spicules of Pennsylvanian Age from Illinois and Indiana."

H. C. VANDERPOOL, of the Rycade Oil Corporation, Houston, Texas, has an article on "Cretaceous Section of Maverick County, Texas," in the September number of the *Journal of Paleontology*.

D. DALE CONDIT, Western Gulf Oil Company, Los Angeles, California, is the author of an article in the September number of the *Journal of Paleontology* on "Age of the Kreyenhagen Shale in Cantua Creek-Panoche Creek District, California."

VAN H. MANNING announces that he has resigned as vice-president and director of research and engineering for the Petroleum Research Corporation, and that he will engage in consulting practice pertaining to the petroleum industry. His office will be at 88 Ascan Avenue, Forest Hills, Long Island, New York.

HENRY V. HOWE, Louisiana State University, Baton Rouge, Louisiana, has an article on "The Genus *Bolivinella* in the Oligocene of Mississippi," in the *Journal of Paleontology* for September.

W. L. F. NUTTALL, Longfield, Madingley Road, Cambridge, England, has an article on "Eocene Foraminifera from Mexico," in the September issue of the *Journal of Paleontology*.

WILLIAM J. MILLARD, of New York City, has been admitted to partnership in the firm of HUNTLEY and HUNTLEY, geologists, with offices in the Grant Building, Pittsburgh, Pennsylvania.

The James Hall geological library, consisting of many rare reprints and many volumes of the early New York State Museum Reports as well as the Natural History and Paleontologic Reports of New York, acquired by the Walker Museum at the University of Chicago when it purchased the Hall paleontologic collection, is being disposed of either for cash or paleontologic exchange. Additional information may be obtained from CAREY CRONEIS, department of geology, Walker Museum, University of Chicago.

L. W. BLAU has recently been named head of the geophysics research department of the Humble Oil Company, with headquarters at Houston, Texas.

JAMES A. Tong, who has recently completed his work for the degree of Doctor of Philosophy at The Johns Hopkins University, has been appointed chief geologist for the Standard Oil Company of New York in Venezuela. Mr. Tong is now in Venezuela.

ALBERT W. GILES, of the University of Arkansas, Fayetteville, Arkansas, is the author of an article on "Controls of Geological Climates," in the September issue of *The Pan-American Geologist.*

N. H. DARTON, of the United States Geological Survey, spoke before the Houston Geological Society, Houston, Texas, October 4, telling about the progress on the geological map of Texas, which he is compiling and which is almost completed.

A. W. WEEKS, district geologist for the Shell Petroleum Corporation at San Antonio, Texas, has returned from a three weeks' vacation in Michigan, Wisconsin, and Illinois.

Geologists who have been doing surface and subsurface work on the Permian beds will be glad to know that considerable approval is being expressed of the proposal to hold a symposium on the northern Permian basin (western Oklahoma and vicinity). The suggestion was made to try to arrange such a group of papers for the San Antonio meeting of the Association, but the desirability of more field work and a meeting closer to the region concerned have resulted in its postponement until 1932.

Officers of the Association visited several geological societies in Texas last month to make plans for the Sixteenth Annual Meeting to be held at San Antonio, March 19-21, 1931, and to present facts about the growth and activity of the Association. President SIDNEY POWERS, of Tulsa, Oklahoma; past-president J. Y. SNYDER, of Shreveport, Louisiana; first vice-president R. D. REED, of Los Angeles, California; and second vice-president MARVIN LEE, of Wichita, Kansas, spoke at a luncheon of the San Antonio Section on October 20; POWERS, REED, and LEE spoke at a meeting of the Houston Geological Society on October 22; FREDERIC H. LAHEE joined the speakers at a luncheon of the Dallas Petroleum Geologists on October 23 and at a dinner of the Fort Worth Geological Society that night; and POWERS, REED and LAHEE spoke at a meeting of the West Texas Geological Society at San Angelo on October 23.

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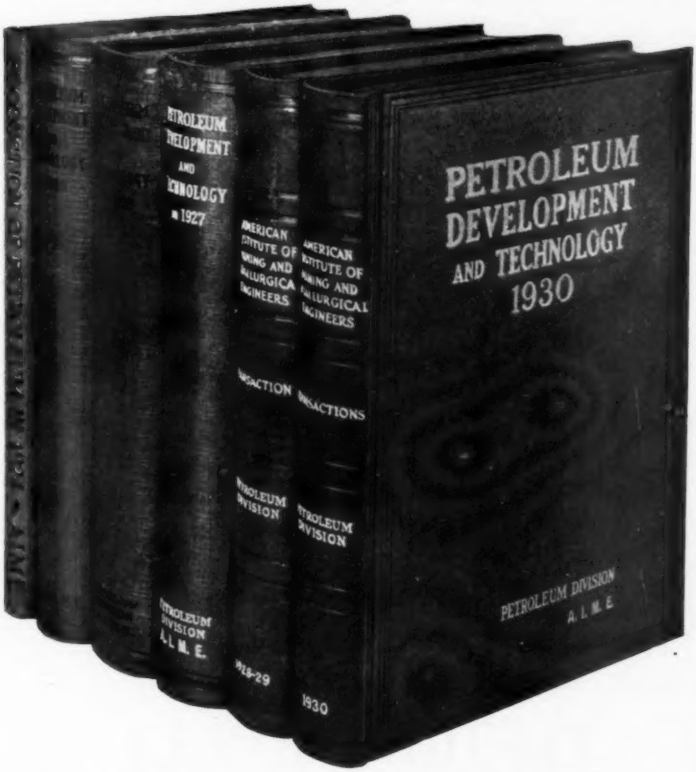

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